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Remote Sensing Study of Electric Generating Station Thermal Discharges to Barnegat Bay and Great Egg Harbor, NJ

National Field Investigations Center-Denver, Colo

Prepared for

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An aerial remote sensing study of thermal discharges to New Jersey coastal waters from two large thermal-electric generating stations was conducted on 13 July 1973. The study encompassed the Great Egg Harbor Bay and the central portion of Barnegat Bay. Thermal discharges evaluated were from the Oyster Creek Nuclear Generating Station.

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ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF ENFORCEMENT

REMOTE SENSING STUDY
OF
ELECTRIC GENERATING STATION THERMAL DISCHARGES
TO
BARNEGAT BAY AND GREAT EGG HARBOR
NEW JERSEY

NATIONAL FIELD INVESTIGATIONS CENTER-DENVER
DENVER, COLORADO
and
REGION II
NEW YORK, NEW YORK

SEPTEMBER 1973

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GLOSSARY OF TERMS

cfs	- Flow rate given in cubic feet per second = 0.0283 cubic meters per second or 28.3 liters per second
cm	- Length in centimeters = 0.3937 in. or 0.03281 ft.
gpm	- Flow rate in gallons per minute = 0.0631 liters per second
km	- Distance in kilometers = 0.621 miles
km^2	- Area in square kilometers = 100 hectares or 0.3861 square miles
knot	- Velocity in nautical miles per hour = 1.15 statute miles per hr = 1.845 kilometers per hour
l	- Volume in liters = 0.2642 gallons
m	- Length in meters = 3.281 feet or 1.094 yards
M	- Mega, a prefix for million = 10^6
m^3/day	- Flow rate in cubic meters per day = 0.000264 million gallons per day
m^3/sec	- Flow rate in cubic meters per sec = 22.8 million gallons per day = 35.3 cubic feet per sec
mgd	- Flow rate in million gallons per day = 3,785 cubic meters per day
mm	- Length in millimeters = 0.1 centimeter
ppm	- Concentration given in parts per million parts
°C	- Temperature in degrees Centigrade = 5/9 (°F-32)
°F	- Temperature in degrees Farenheit

I. INTRODUCTION

An aerial remote sensing study of thermal discharges to New Jersey coastal waters from two large thermal-electric generating stations was conducted on 13 July 1973. The study was undertaken at the request of the Surveillance and Analysis Division, Region II, Environmental Protection Agency, New York, New York.

The study encompassed the Great Egg Harbor Bay and the central portion of Barnegat Bay. Thermal discharges evaluated were from the Oyster Creek Nuclear Generating Station operated by Jersey Central Power and Light Company on Barnegat Bay and the B. L. England Generating Station on Great Egg Harbor Bay. Infrared imagery of the study areas was obtained using infrared line scanners mounted in high-performance reconnaissance aircraft. This imagery along with ground truth water temperature data was used to characterize the observed thermal fields or plumes. Water temperatures were evaluated with respect to applicable water quality standards.

The results of this study will be used in the preparation of Environmental Impact Statements for the two Bays and the subsequent drafting of thermal discharge permits for the two power generating facilities.

II. SUMMARY AND CONCLUSIONS

Airborne thermal infrared sensors were used to record the characteristics of thermal discharges from the Oyster Creek Nuclear Generating Station and the B. L. England Generating Station on 13 July 1973, a period of peak power demand and high receiving water temperatures. Ground truth in the form of surface water temperatures at various points in the thermal plumes was obtained by field crews at the time of flight.

Isothermal maps depicting areas of equal surface water temperature were prepared from the infrared imagery. Actual temperatures of the isotherms were determined from the ground truth data. The isothermal maps characterized the behavior of the thermal plume under known hydrologic and tidal conditions. Evaluations of the observed thermal plumes with respect to applicable water quality criteria were made and violations defined. Results of the investigation of each study area are summarized below.

BARNEGAT BAY

1. The Oyster Creek Nuclear Generating Station is a nuclear fueled, thermal-electric power plant operated by the Jersey Central Power and Light Company. With a generating capacity of 620 megawatts, the facility began full-scale operation in 1970. Summertime cooling water use is about 29 m^3/sec (1,020 cfs or 660 mgd). Heated cooling water is discharged to Oyster Creek about 3.2 km (2 mi) upstream of Barnegat Bay and is conveyed to the Bay by the Creek.

2. Barnegat Bay is a shallow embayment paralleling the New Jersey coastline. At the mouth of Oyster Creek the Bay is about 7 km (4 mi) wide. Much of the Bay is shallow (less than 1 m deep) with mid-bay depths averaging 2 to 4 m (7 to 13 ft). The tidal range is small, less than 0.2 m (0.6 ft).

3. The observed thermal field in Barnegat Bay extended from the mouth of Oyster Creek to Island Beach, the full width of the Bay. Surface water temperatures in the Bay ranged from ambient receiving water temperatures of 23.5°C (74.3°F) to a peak of 28.1°C (82.5°F) at the mouth of Oyster Creek. The thermal field extending completely across the Bay was more than 0.8°C (1.5°F) above ambient temperatures. This represents a point of non-compliance with the proposed effluent guidelines that limit water temperatures more than 0.8°C above ambient to less than two-thirds of the surface area at any cross-section.

4. Oyster Creek has not been designated as a mixing zone. Surface water temperatures in the Creek ranged from 29.0°C (84.0°F) to 31°C (88°F). The surface temperature of Oyster Creek from the cooling water discharge point downstream for about 310 m (1,020 ft) exceeded the 29.4°C (85°F) maximum limit specified by the New Jersey Water Quality Standards. It is probable that essentially the entire flow in Oyster Creek was cooling water. Therefore, the entire streamflow had a temperature far in excess of an 0.8°C rise above ambient temperature. Such a temperature rise would be limited to less than 25 percent of the cross-sectional area of the stream by the general effluent guidelines. Oyster Creek was thus not in compliance with this proposed limitation.

GREAT EGG HARBOR BAY

1. The B. L. England Generating Station is a fossil fueled, thermal-electric power plant operated by the Atlantic City Electric Company. With a generating capacity of 290 megawatts, the facility has been in operation since 1962. Cooling water use averages about 12.4 m^3/sec (435 cfs or 282 mgd) with heated water discharged directly to Great Egg Harbor Bay.

2. Great Egg Harbor Bay is an estuary of the Great Egg Harbor and Tuckahoe Rivers. The Bay is about 10 km (6 mi) long with an average width of 2 to 3 km (1 to 2 mi). Much of the Bay is shallow with depths less than 1 m but channel depths as great as 11 m (35 ft) occur. The tidal range is large, averaging 1.2 m (3.8 ft).

3. Under ebb tide conditions, the thermal plume in Great Egg Harbor Bay, created by the B. L. England cooling water discharge, moved in an easterly direction along the southshore of the Bay, and then turned in a northeasterly direction at Golders Point near the mouth of Peck Bay. This plume movement was influenced by ebb tide currents in both Great Egg Harbor Bay and Peck Bay. Different plume characteristics would be expected under flood tide conditions.

4. Surface water temperatures in the thermal plume in Great Egg Harbor Bay ranged from 22.8°C (73°F) (ambient) to a maximum of 29.4°C (85°F). The maximum temperature limit (29.4°C) specified by the New Jersey Water Quality Standards was exceeded only at the discharge point. At cross-sections across Great Egg Harbor Bay east of the Garden State Parkway Bridge and across the entrance of Peck Bay, more than two-thirds

of the surface water was heated to a temperature exceeding 0.8°C above ambient in disagreement with the proposed general guideline.

5. This study has shown that remote sensing techniques could be implemented into a compliance monitoring program to quickly and cost effectively ascertain the real time behavior of thermal discharges and the resultant thermal plumes. A procedure could readily be developed to apply the aerial thermal data to each discharge to document compliance or noncompliance with water quality standards and to evaluate the effectiveness of proposed effluent (thermal) guidelines.

III. BACKGROUND INFORMATION

DESCRIPTION OF STUDY AREAS

This study encompassed the estuarine waters of Barnegat Bay and Great Egg Harbor Bay on the Atlantic coast of New Jersey [Figure 1]. Although similar in climatic conditions and general locations with respect to the Atlantic Ocean, the two study areas have significant differences in physical, tidal and hydrologic characteristics as discussed in the following sections.

Barnegat Bay

Located about 50 km (31 mi) NNE of Atlantic City, in Ocean County, Barnegat Bay is a long, narrow embayment paralleling the New Jersey coastline [Figure 2]. Extending from Toms River on the north to Manahawkin Bay on the south, a distance of about 30 km (19 mi), the Bay has a width ranging from about 3 to 7 km (2 to 4 mi). About one-third of the Bay is very shallow (less than 1 m depth) with depths greater than 4 m occurring only in the narrow channels leading to Barnegat Inlet, the narrow opening connecting the Bay with the Atlantic Ocean. Mid-Bay depths in the area of interest average 2 to 4 m (7 to 13 ft).

Two types of topography surround the Bay. On the ocean side narrow, sandy barrier islands separate the estuarine and ocean waters. Island Beach is to the north of Barnegat Inlet and Long Beach to the south. Barnegat Inlet is the only break in the barrier islands along 64 km (40 mi) of coastline.

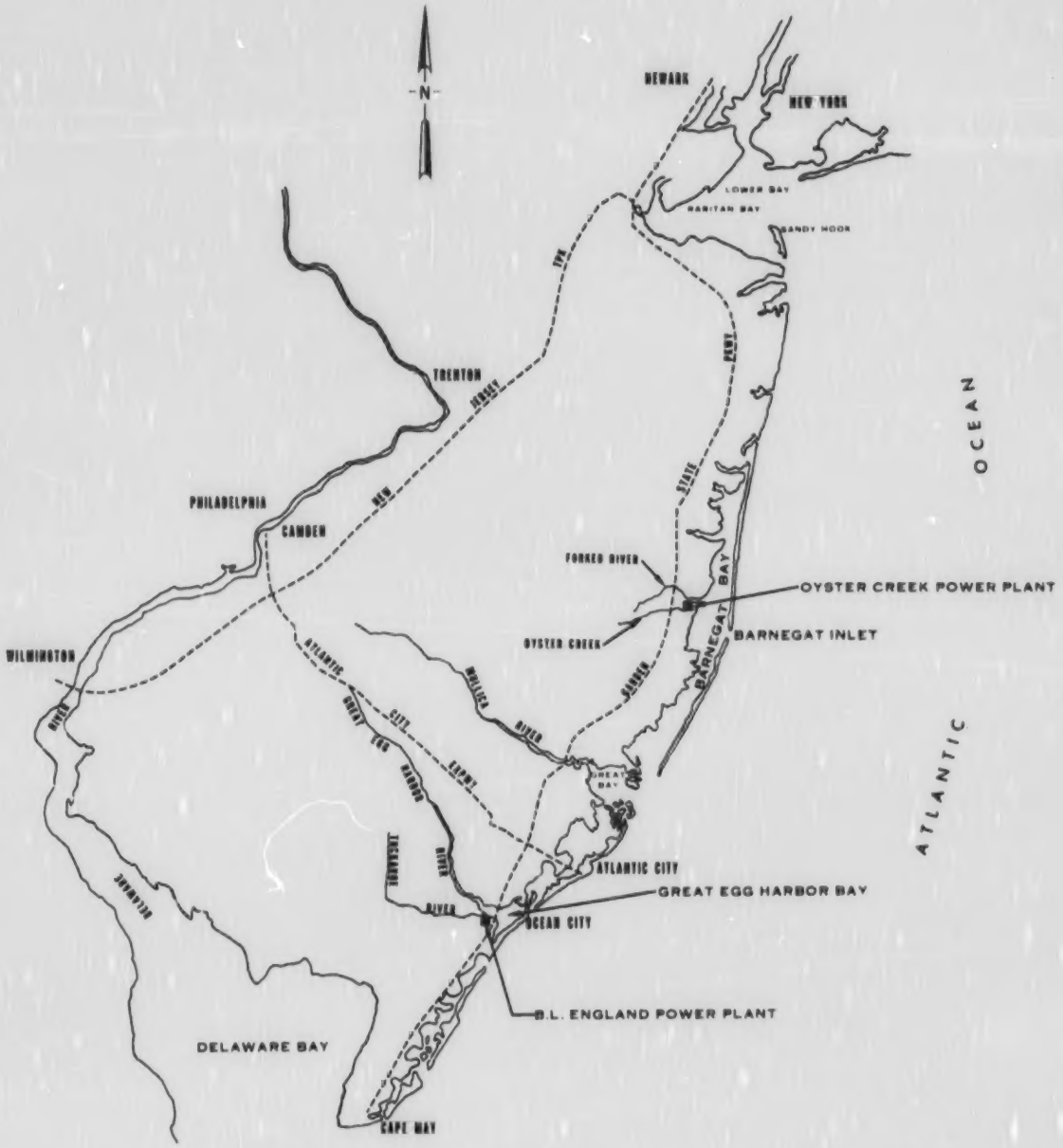


Figure 1. Location Map

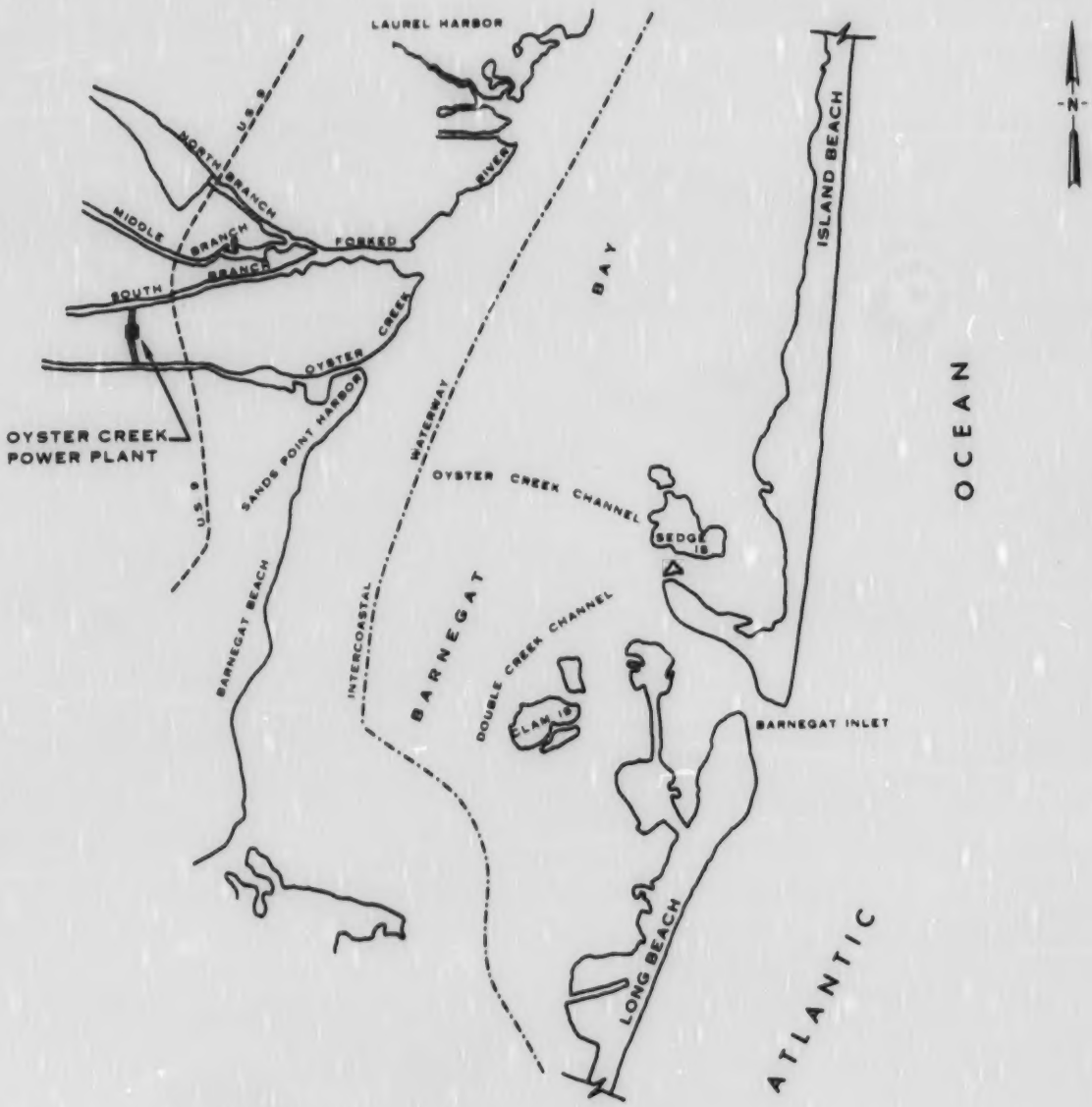


Figure 2. Central Barnegat Bay

Inland the Bay is bordered by tidal marshes, tidal streams and lowlands. Much of the marsh land has been dredged to form marinas and housing developments located on canals. In addition, navigation channels have been dredged in the mouths of several of the streams. The Intracoastal Waterway traverses the length of the Bay.

Streams entering the Bay are small and freshwater inflow is minor (less than 28 m^3/sec or 1000 cfs) relative to tidal interchange from the ocean. In the area of Barnegat Bay considered in this study, the Forked River and Oyster Creek are the two streams of interest. Oyster Creek has a drainage area of less than 34 sq km (13 sq mi) and an average annual flow around 1.7 m^3/sec (60 cfs). Flow is relatively uniform throughout the year with highest runoff occuring during late winter and low flow at mid-summer.

The Forked River, formed by the confluence of the North and South Branches near its mouth, has a drainage area estimated to be about 104 sq km (40 sq mi). Flow records are not available but the average annual flow should be in the range of 2.3 to 4.5 m^3/sec (80 to 160 cfs).

Tidal information is available for two locations in the vicinity; Barnegat Inlet and Oyster Creek Channel off Sedge Island. The Barnegat Inlet station reflects open ocean conditions. Tides are semi-diurnal with a mean range of 1.0 m (3.1 ft) and a range during spring tides of 1.2 m (3.8 ft).

The effect of the narrow Barnegat Inlet on tides in Barnegat Bay is reflected by tidal conditions in the Oyster Creek Channel. Tides at Sedge Island about 3 km inside the inlet lag about 2 hr 36 min behind

open ocean tides. The tidal range is reduced to only about 0.2 m (0.6 ft). The mouth of Oyster Creek is located almost 3 km (2 mi) directly across the Bay from Oyster Creek Channel. Tides at the mouth of Oyster Creek would thus be expected to have a similar range as at Oyster Creek Channel and lag a few minutes behind.

Wind conditions affect the tides in the Bay and may add to or reduce the normal lunar tide range.

The average annual air temperature at Toms River located about 13 km (8 mi) north of Oyster Creek is 11°C (52°F). Average monthly air temperatures range from -1°C (31°F) in February to 24°C (75°F) in July. Temperature extremes are moderated by proximity to both Barnegat Bay and the Atlantic Ocean. Record temperature extremes range from a low of -16°C (3°F) to a high of 35°C (95°F). Proximity to marshes and open water areas results in high relative humidity most of the year.

Great Egg Harbor Bay

In contrast to Barnegat Bay, the Great Egg Harbor Bay is a typical estuary with significant freshwater inflow for its size and with a large inlet to the ocean. These conditions produce substantially different tidal and hydrological characteristics than at Barnegat Bay.

Great Egg Harbor Bay, the drowned mouth of the Great Egg Harbor River, is located about 15 km (10 mi) southwest of Atlantic City [Figure 3]. The Bay extends inland from Great Egg Harbor Inlet about 10 km (6 mi) with an average width of 2 to 3 km (1 to 2 mi). At the coastline the Inlet is about 1.6 km (1.0 mi) wide narrowing to 1 km

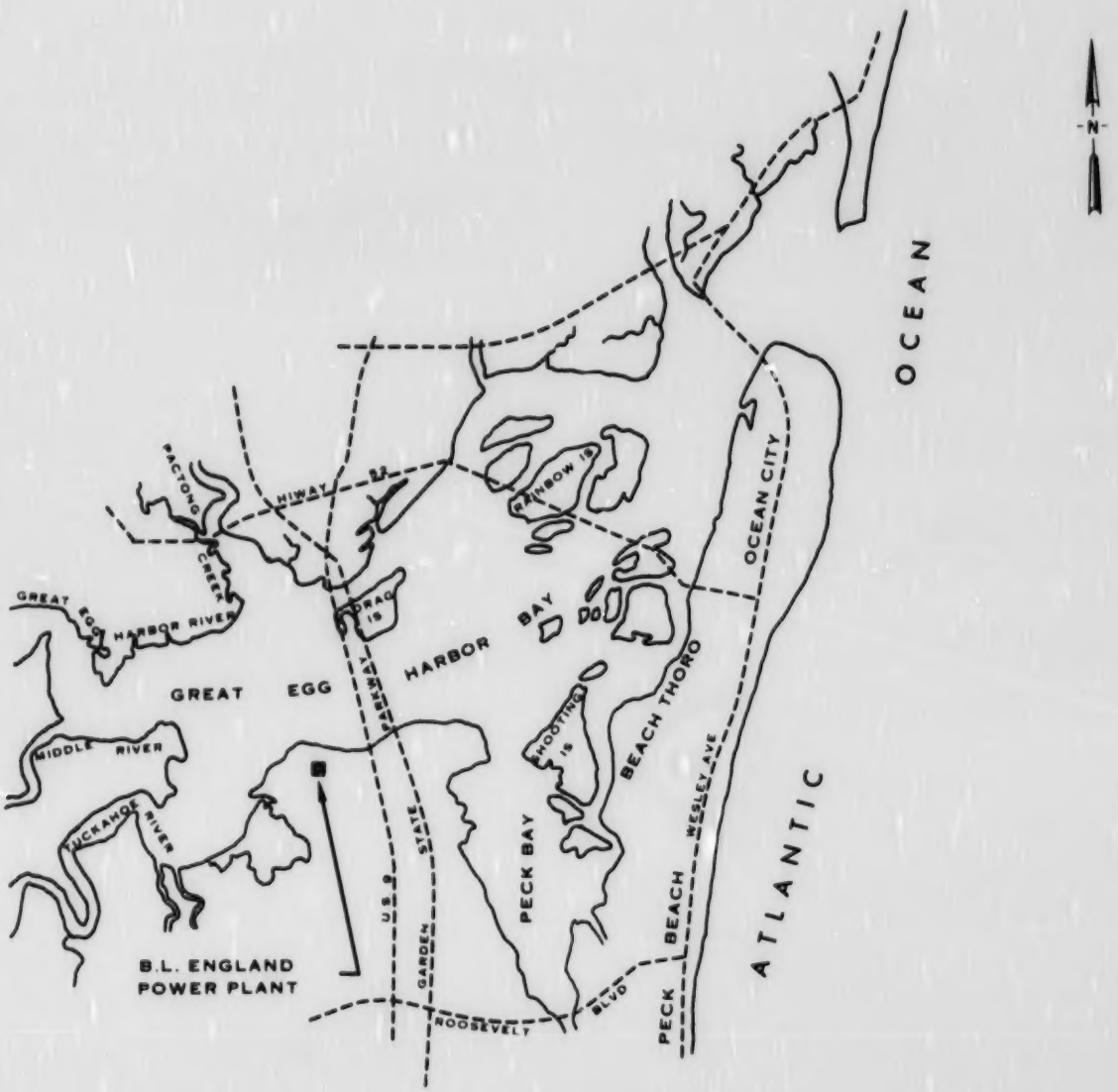


Figure 3. Great Egg Harbor Bay

inside the Bay. Peck Bay, a shallow embayment with an average width of 0.8 km (0.5 mi) extends about 3 km (2 mi) off the south side of the Bay. A series of islands divide the Bay into narrow channels about one-third of its length inland from the Ocean.

Water depths in much of Great Egg Harbor Bay and Peck Bay are less than 1 m (3 ft). In the submerged stream channels and channels between islands, however, tidal currents have scoured areas as deep as 11 m (35 ft).

Topography surrounding the Bay is similar to the Barnegat Bay area with the exception that this area is more highly developed. Ocean City, with a population of 11,000, is located on a peninsula south of Great Egg Harbor Inlet that separates Peck Bay and central Great Egg Harbor Bay from the Atlantic Ocean.

Several natural channels connect the Bay system with other coastal bays. The Intracoastal Waterway traverses Peck Bay and the north end of Great Egg Harbor Bay.

Freshwater inflow to the estuary is provided by Great Egg Harbor River, Tuckahoe River, Patcong Creek, Middle River, and numerous minor tidal tributaries. The Great Egg Harbor River is the largest stream with an estimated drainage area of about 910 sq km (347 sq mi). Average annual streamflow is about 14.7 m^3/sec (520 cfs). Average monthly discharges vary from a high in February and March to a low in July with a high-low ratio of about 4:1.

The Tuckahoe River has an estimated drainage area of about 310 sq km (102 sq mi) and an average annual flow of about 4.0 m^3/sec (140 cfs).

Flow variations are similar to the Great Egg Harbor River. Patcong Creek and Middle River provide only minor freshwater inflow.

Tidal information is available for a number of locations in the Bay. As a result of the large inlet to the ocean, differences in average tidal ranges between points in the Bay are small and approximate open ocean conditions. At Great Egg Harbor Inlet the mean and spring tide range are 1.2 m (3.8 ft) and 1.4 m (4.6 ft) respectively. Corresponding tide ranges in Great Egg Harbor Bay near the confluence of the Great Egg Harbor and Tuckahoe Rivers are 1.1 m (3.6 ft) and 1.3 m (4.4 ft). Lag time for tidal changes is small with high water and low water occuring 32 and 62 minutes later, respectively, at the Bay station in comparison to the Inlet station. Tidal effects extend up the Tuckahoe River for several km and more than 25 km up the Great Egg Harbor River. At Mays Landing (20 km upstream from the mouth) tides in the Great Egg Harbor River have a mean range of 1.2 m (4.0 ft) and lag about 2 1/2 hr behind tide changes at Great Egg Harbor Inlet. Tides in both rivers and upper reaches of the Bay are affected by flood flows in the rivers.

Climatic conditions are similar to those at Barnegat Bay. At Atlantic City, about 15 km (10 mi) NE of Great Egg Harbor Bay, the average annual air temperature is about 12°C (54°F) with mean monthly temperatures ranging from 3°C (37°F) in January to 23°C (73°F) in July. Record temperatures range from -12°C (11°F) to 34°C (93°F). Relative humidity is high much of the year.

DESCRIPTION OF POWER PLANTS

Oyster Creek Nuclear Generating Station

Located on Barnegat Bay [Figure 2], this thermal-electric power plant, a nuclear fueled facility, is operated by Jersey Central Power and Light Company to provide base power generation for the Northeast energy market. Plant operation began in late 1969 with intermittent trial operations continuing through most of 1970. Full-scale operation was initiated during the Winter of 1970-1971. Generating capacity is about 620 megawatts.

The plant has a once-through cooling water system with the water supply obtained from the South Branch of the Forked River. Summertime cooling water use is about 29 m^3/sec (1,020 cfs or 660 mgd). The intake point is located about 2.5 km (1.6 mi) upstream from the confluence of the North and South Branches of the Forked River and about 4 km (2.5 mi) upstream from Barnegat Bay. South Branch is tidal at the intake point. Average freshwater inflow to the Forked River at its mouth is about 7 to 17 percent of summer cooling water use. During normal and low streamflow conditions in the Forked River, the cooling water supply is primarily saline Bay water. Only during high runoff stages does the water supply become primarily freshwater.

Heated cooling water is discharged to Oyster Creek about 3.2 km (2 mi) upstream from Barnegat Bay. As average freshwater flow in Oyster Creek is about 1.7 m^3/sec (60 cfs), except for high runoff stages, the natural streamflow provides little cooling or dilution of salinity of the cooling water flow. Oyster Creek serves as a canal to convey the cooling water to Barnegat Bay.

B. L. England Generating Station

This fossil fuel (coal and crude oil) burning thermal-electric power plant, located on the south shore of Great Egg Harbor Bay [Figure 3], is operated by the Atlantic City Electric Company. Plant operation began in 1962. The plant has two generating units with the total capacity of about 290 megawatts.

The plant uses water from Great Egg Harbor Bay for once-through cooling purposes, returning the heated water to the Bay near the intake point. A narrow (25 m) channel conveys the discharge about 80 m (260 ft) offshore.

A Refuse Act Permit Program application (Application No. 2SD-0X0-3-000432) was filed for the plant in June 1971.[1/] The application indicates that the plant has a total of 11 wastewater discharges. Nine of the discharges, including boiler blowdown, intake screen washdown, boiler slag sluicewater, and other miscellaneous small wastestreams, total only 0.13 m^3/sec (3 mgd). Cooling water use for Unit No. 1 averages 3.7 m^3/sec (85 mgd) with a range of 2.8 to 5.5 m^3/sec (63 to 126 mgd). For Unit No. 2, cooling water use averages 4.5 m^3/sec (102 mgd) with a maximum of 6.7 m^3/sec (153 mgd). Total water use for the plant under summer conditions reaches a maximum of 12.4 m^3/sec (282 mgd or 435 cfs).

Average Bay water intake temperatures range from 4°C (40°F) in the Winter to 24°C (75°F) in the Summer.[1/] Under summer conditions, cooling water discharge temperatures range from 24°C (75°F) to a maximum of 38°C (100°F) with an average of 29°C (85°F). Comparable winter temperatures are a range of 12°C (53°F) to 24°C (75°F) with an average of 16°C (60°F).

Maximum temperatures as high as 48°C (119°F) were reported for the miscellaneous waste streams but the volume of flow is minor.

APPLICABLE WATER QUALITY STANDARDS AND PROPOSED EFFLUENT GUIDELINES

New Jersey adopted water quality standards for coastal waters under provisions of the Water Quality Act of 1965. These standards include criteria that limit changes in the temperature of receiving waters induced by thermal discharges.[2/]

Barnegat Bay and Great Egg Harbor are classified Class TW-1 which are tidal waters approved as sources of public, potable water supply. These waters are to be suitable for shellfish harvesting where permitted. These waters are also to be suitable for the maintenance, migration and propagation of the natural and established biota, and for primary contact recreation, industrial and agricultural water supply, and any other reasonable uses.

The existing temperature criteria for Class TW-1 waters are:

> "No heat may be added except in designated mixing zones, which would cause temperatures to exceed 85°F (29.4°C), or which will cause the monthly mean of the maximum daily temperature at any site, prior to the addition of any heat, to be exceeded by more than 4°F (2.2°C) during September through May, or more than 1.5°F (0.8°C) during June through August. The rate of temperature change in designated mixing zones shall not cause mortality of the biota."[3/]

Mixing zones are defined as localized areas of surface waters into which wastewater effluents, including heat, may be discharged for the purpose of mixing, dispersing, or dissipating such wastewater without creating nuisance or hazardous conditions. It is specified in the Water Quality Criteria that the mixing zones may be designated by the

New Jersey Department of Environmental Protection. Presently, New Jersey's existing standards contain no written guidelines for the designation of mixing zones.

In early 1973, effluent guidelines were proposed that would cause the above-quoted criteria to read as follows:

> "No heat may be added, except in designated mixing zones, which would cause temperatures to exceed 85°F (29.4°C), or which would cause the monthly mean of the maximum daily temperature at any site, prior to the addition of heat to be increased by more than 4°F (2.2°C) during September through May, or to be increased by more than 1.5°F (0.8°C) during June through August. The rate of temperature change in designated mixing zones shall not cause mortality of the biota."3/

In addition to these temperature criteria, the following general guidelines have been proposed for the establishment of "mixing zones" and "zones-of-passage":

> "Mixing Zones:....the total area and/or volume of a body of water assigned to mixing zones shall be limited to that which will not interfere with biological communities or populations of important species to a degree which is damaging to the ecosystem nor diminish other beneficial uses disproportionately."

> "Zones of Passage:...in...estuaries and coastal waters, zones of passage are considered to be continuous water routes of the volume, area and quality necessary to allow passage of free-swimming and drifing organisms with no significant effects produced on their populations. These zones must be provided wherever mixing zones are allowed."3/

Specifically for "thermal mixing zones" the following guideline has been proposed:

> "Thermal Mixing Zones: As a guideline..., thermal mixing zones shall be limited to no more than 1/4 of the cross-sectional area and/or volume of the flow of stream or estuary, leaving at least 3/4 free as a zone of passage, including a minimum of 1/3 of the surface measured from shore to shore at any stage of tide or flow."3/

The numerical limits were derived from recommendations of the National Technical Advisory Committee (NTAC) report on water quality criteria.[4/] The intent of the NTAC recommendations was to maintain water temperatures below maximum limits detrimental to aquatic life. The temperature-rise limits were designed to control the allowable heat load discharged to a given body of water while allowing normal daily and seasonal temperature fluctuations to occur. The percentage of the cross-sectional area of the receiving water with elevated temperatures was limited to provide for zones of passage so that migrating or drifing aquatic life and organisms could pass without being blocked or killed by a thermal barrier.

IV. STUDY TECHNIQUES FOR THERMAL DISCHARGES

AIRCRAFT AND FLIGHT DATA

This remote sensing mission was carried out by two high performance aircraft specifically designed and equipped for aerial reconnaissance work. The two aircraft independently flew each target area to provide primary and backup coverage. Both aircraft carried the sensors discussed below.

The flight parameter data listed below provide the specific values of the aerial reconnaissance variables.

Date of Flight: 13 July 1973

Time of Flight: 1100 to 1300 Hours EDT

Target Areas : Central Barnegat Bay, Great Egg Harbor Bay

Air Speed of Flight: 660 to 740 km/hr (360 to 400 knots)

Aircraft Altitude Above Water Level: 915 m (3000 ft)
and 1830 m (6000 ft)

Sensors Used: Infrared Line Scanner

SENSOR DATA

An AN/AAS -18 Infrared Line Scanner (IRLS) was the sensor used for this study. The sensor is located on the underside of the aircraft as shown in Figure 4. While in operation, it images an area along the flight path of the aircraft. The width of the imaged area is dependent upon aircraft altitude and is encompassed by a 120° field-of-view in cross-track or perpendicular to the flight path (shown below).

LEGEND

1 KS-87 FRAMING CAMERAS

2 INFRARED LINE SCANNER

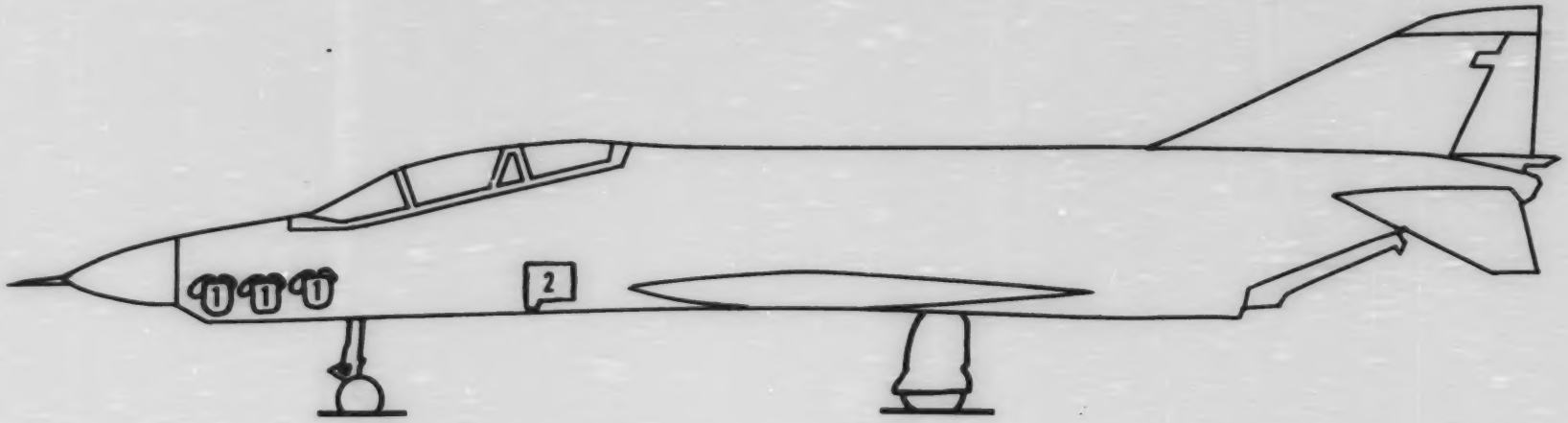


Figure 4. Aircraft Sensor Locations

16a

Field-of-View of the IRLS

An IRLS converts variations in infrared energy emissions from objects of different temperatures into a thermal map. The three basic parts of an IRLS are the scanner optics, a detector array, and a recording unit. The scanner optics collect the infrared emissions from ground and water areas and focus them on the detectors [Figure 5].

The detectors, cryogenically cooled to 26° Kelvin, convert the infrared energy collected by the scanner optics into an electronic signal. This signal is processed electronically and subsequently transformed into visible light through a cathode ray tube. This light is then recorded on ordinary RAR black-and-white film measuring 12.6 cm (5 in.) in width. The recorded thermal map is 10 cm (4 in.) wide and its length depends upon the length of a particular line of flight being imaged.

The IRLS has a sensitivity bandwidth from 8 to 14 microns, the so called thermal band of the electromagnetic spectrum. Applying Wien's

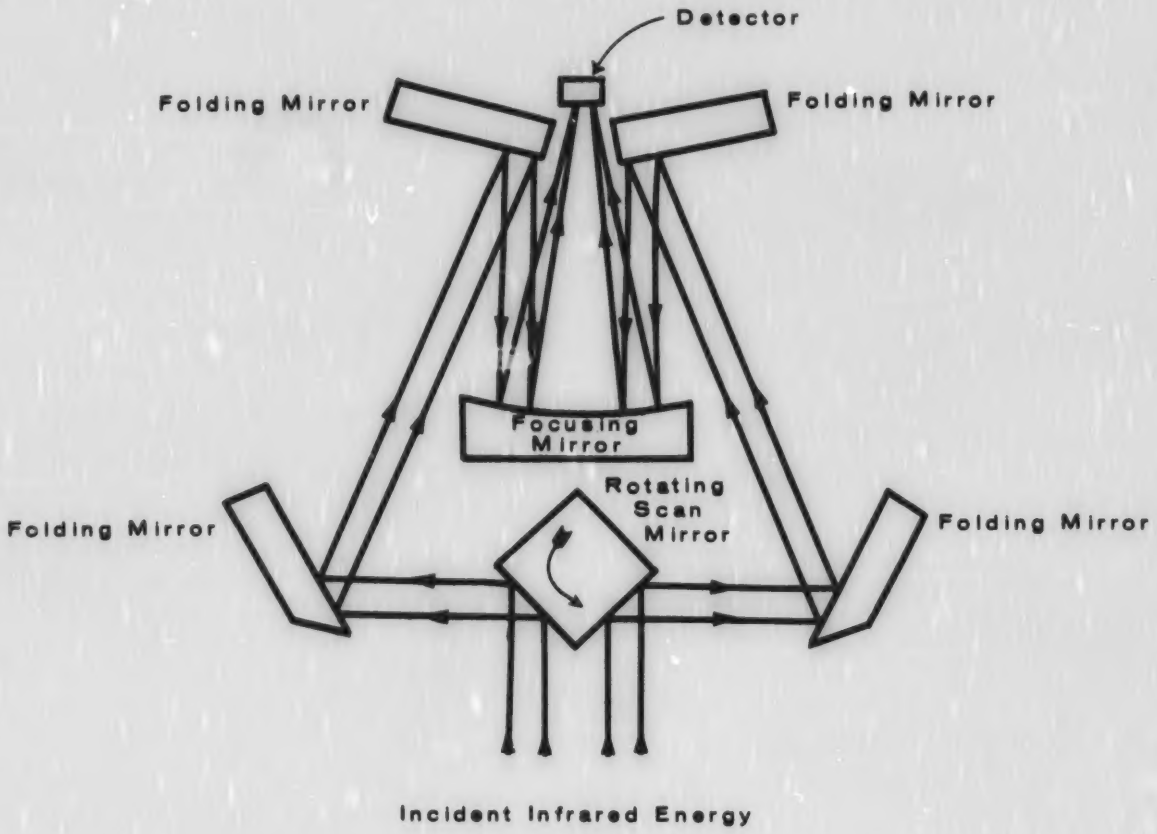


Figure 5. IRLS Optical Collection System

Displacement Law, this represents a temperature band from -66°C to 89°C. The system has an instantaneous field-of-view of 1 milliradian by 1 milliradian. The total field of view is achieved by the rotating mirror in the optical collection system, which is 120° by 1 milliradian. The measured noise equivalent temperature (N.E.T.) of the IRLS is 0.32°C with 100 percent probability of target detection. This represents an effective measurement of the temperature resolution of the system.

GROUND TRUTH

The Surveillance and Analysis Division, Region II, EPA, obtained ground truth, in the form of near-surface water temperatures, simultaneously with the time-of-flight. The water temperature data was measured at discrete points along straight line transects. In the case of Barnegat Bay, two transects were made extending in northeasterly and southeasterly directions from the mouth of Oyster Creek. The northeasterly transect had three data points and the southeasterly transect contained eleven discrete data points. Three surface water temperatures were also obtained from within Oyster Creek.

Two linear transects were also made in Great Egg Harbor Bay. The main transect extended in a north northeasterly direction from the effluent point of the B. L. England Generating Station. It contained eight discrete data points at which surface water temperatures were taken. The second transect was symetrically perpendicular to and intersected the first about 340 m (1100 ft) into the Harbor. It contained six discrete data points.

The accuracy of the contact instrumentation used to obtain the surface water temperatures was ± 0.1°C.[5/] It is estimated that the precise location of the discrete water-temperature data points was known to within ± 30 meters.

DATA INTERPRETATION AND ANALYSIS

All data interpretations and analyses were carried out on the original black and white film negative used to record the infrared data aboard the aircraft. Photographic prints were not used because of the added errors of an additional image generation.

Each thermal plume image or map, associated with the two power plant discharges under study, was plotted with respect to US Department of Commerce Nautical Charts (Scale 1:40,000) to determine the infrared image scale. To evaluate consistency this scale was compared to the empirical scale derived from the effective focal length of the IRLS and the altitude of the aircraft above water level. The respective image scale is included on each thermal map in this report.

In the black-and-white IRLS film, temperature levels are represented by various shades of gray in the negative format or rendition. Areas of low density (clear film) represent cooler temperatures and as the temperature of a particular target becomes warmer the density of gray in the film also increases. Positive prints presented in this report reflect the reverse of the negative film. Cool areas are dark while the warm areas are light gray.

A Spatial Data 704 Image Analyzer was used to convert the infrared images into isothermal maps. Isothermal maps delineate areas with the

same temperature (isotherms). The Image Analyzer uses a technique called density slicing to divide the density range on a given infrared image into 12 increments. Each increment thus represents a particular density of gray on the image and a narrow temperature range closely approximating an isotherm. The density value of each increment is accurate to within 0.03 density units over a range of 0 to 2 (density). Each density increment is displayed on the Image Analyzer screen in a particular color. An isothermal map was prepared by tracing directly from the color rendition on the Analyzer display screen.

The actual temperature of each isothermal area on the map was determined by first comparing it with a physical plot of the water temperature data obtained in the field at flight time. Each density value or increment represents a particular water temperature. These are derived from calibration curves obtained empirically from the gray density levels on the negative corresponding to the locations at which the ground truth water temperatures were taken at the time of flight. These curves were used to interpolate temperatures for isotherms in areas where no ground truth data points were located. They covered a rather large temperature differential (6 to 8°C or 10 to 14°F) between the power plant effluents and the background or ambient receiving waters. From the calibration curves the absolute temperature of each isotherm (colored increment) delineated by the Image Analyzer was thus determined.

An important factor must be mentioned at this point. The IRLS will only record water surface temperatures since water is opaque in this region of the infrared spectrum. The maximum depth penetration

in either fresh or salt water is 0.01 cm. Therefore, a submerged thermal discharge can be detected from an aircraft with an IRLS only if the the warm wastewater reaches the surface of the receiving body of water. The isothermal maps developed by this study thus represent surface temperatures only and may not necessarily reflect subsurface temperature distributions.

ERROR ANALYSIS

Limitations can be placed on the accuracy or uncertainty of the absolute value of water temperatures represented by the isothermal maps developed by this study. The three significant sources of error affecting the data are the resolution of the IRLS, the accuracy of the Image Analyzer, and the accuracy of the instrumentation used in obtaining ground truth. These sources have the following error values:

(1) $\Delta t_1 = \Delta t_{IRLS} = \pm 0.32°C$ (measured system N.E.T.)

(2) $\Delta t_2 = \Delta t_{\text{Image Analyzer}} = \pm 0.10°C$ (film density accuracy)

(3) $\Delta t_3 = \Delta t_{\text{ground truth inst.}} = \pm 0.10°C$ (accuracy of instrument)

By using the method of root-sum-squares, the magnitude of the total possible error range can be estimated as follows:

$$\Delta t_{total} = \pm \left[\sum_{i=1}^{3} (\Delta t_i)^2\right]^{\frac{1}{2}}$$

$$= \pm \left[(0.32)^2 + (0.10)^2 + (0.10)^2\right]^{\frac{1}{2}}$$

$$\Delta t_{total} = \pm 0.35°C \ (\pm 0.63°F)$$

The reported temperature values are thus accurate to within $\pm$ 0.35°C (0.63°F).

No atmospheric corrections were applied to these thermal data under the assumption that the atmospheric effect was constant and would not induce a significant effect since the film was directly calibrated by the water temperatures measured during the time of flight. Any influence of the air column between the aircraft and the water surface would be taken into account by the calibration process, assuming a constancy of the entire air column in the target area.

V. RESULTS AND EVALUATION OF THERMAL DATA ANALYSIS

This section presents the results of the analysis of the temperature data obtained by aerial reconnaissance and ground surveys. Tidal conditions, weather and streamflow conditions existing at the time of flight are summarized and the behavior of the thermal plumes evaluated with respect to these conditions. Observed temperature conditions are compared to applicable water quality standards and violations of those standards are described.

BARNEGAT BAY

The Oyster Creek Nuclear Generating Station discharges cooling water to Oyster Creek about 3 km (2 mi) above its mouth [Figure 2]. The Creek conveys the heated water to Barnegat Bay where it disperses. The resultant thermal plume extends over a significant portion of central Barnegat Bay between the mouth of Oyster Creek and Barnegat Inlet. The entire area affected by the thermal plume was investigated on 13 July 1973.

Environmental Conditions at Time of Flight

Predicted tide conditions for Barnegat Inlet and Oyster Creek Channel are shown in Table V-1.[6/] Actual tide conditions were not measured but prevailing weather conditions and the low tide range in Barnegat Bay would indicate that actual tide conditions were very close to predicted levels. The Oyster Creek Channel tide station is located about 3 km (2 mi) directly across the Bay from the mouth of Oyster Creek. Tide levels at the mouth of Oyster Creek would be

expected to be almost identical to the Oyster Creek Channel station with a slight time lag.

TABLE V-1

PREDICTED TIDE CONDITIONS-BARNEGAT BAY
13 JULY 1973

Location	Time EDT	Tide Level		Tide
		Meters	Feet	
Barnegat Inlet	0050	0.1	0.3	Low Low
	0650	0.8	2.5	Low High
	1250	0.2	0.5	High Low
	1912	1.1	3.7	High High
Oyster Creek Channel (Off Sedge Island)	0328	0.0	0.0	Low Low
	0926	0.2	0.5	Low High
	1528	<0.1	0.1	High Low
	2148	0.7	0.7	High High

Tides at the Oyster Creek Channel lag about 2.6 hr behind tide changes at Barnegat Inlet. At the time of flight the tide at Barnegat Inlet was 1 to 2 hr from high-low tide in the ebb phase with a water height difference of about -0.5 m (-1.6 ft) (referenced to LH Tide). In like manner, the tide at the Oyster Creek Channel was 3.5 to 4 hr from high-low tide in the ebb phase with a water height difference of about -0.05 m (-0.15 ft) representing a nearly static condition in Barnegat Bay.

Weather conditions at the time of flight at selected nearby stations are summarized in Table V-2:

TABLE V-2

WEATHER CONDITIONS - 13 JULY 1973[7]

Parameter	Atlantic City	Newark	Toms River
Air Temperature	27°C (80°F)	26°C (78°F)	24°C (75°F)
Relative Humidity	46%	50%	-
Wind Speed & Direction	22-37 km/hr (12-20 knots, SW)	17-26 km/hr (9-14 knots, SW)	-
Precipitation	0	0	0

Oyster Creek and central Barnegat Bay are approximately midway between Atlantic City and Newark and are 13 km (8 mi) south of Toms River. As the wind was blowing from the southwest at both wind stations during the mission with an average velocity of 20 km/hr (11 knots), it is reasonable to assume that these weather conditions prevailed in the target area at the time of flight.

Estimates of streamflow prepared by the U.S. Geological Survey indicate flow in Oyster Creek exclusive of the power plant discharge was about 1.6 m^3/sec (55 cfs) on 13 July.[8] Streamflow in the Forked River near its mouth (exclusive of power plant intake flows) was estimated at 1.1 m^3/sec (38 cfs). In comparison to cooling water use of 28 m^3/sec (1,000 cfs), these flows were minor. Less than six percent of the outflow from Oyster Creek was freshwater streamflow. Less than four percent of the water supply obtained from the Forked River was freshwater streamflow indicating the cooling water discharge would be essentially the same salinity as Bay water.

Thermal Plume Characteristics

As discussed in Chapter IV, thermal maps were made of central Barnegat Bay from two different altitudes, 915 and 1,830 m (3,000 and

6,000 ft) above water level. The higher altitude map provides the greatest areal coverage while more detail was obtained by the lower altitude flight.

A thermal map showing the location of the Oyster Creek Nuclear Generating Station, Oyster Creek, and the thermal plume in Barnegat Bay is shown in Figure 6. This map is a positive print of infrared imagery recorded at the 1,830 m altitude and has an approximate scale of 1:63,000. As this is a positive image, dark areas are cool and the very light gray or white areas are quite warm. Note that the domain of Oyster Creek is quite warm as depicted by the light gray color. The thermal plume resulting from the outflow from Oyster Creek extends in an eastward direction. The thermal plume disperses very little in the first third of the distance across Barnegat Bay. In the remaining two thirds of the distance, the plume appears to disperse quite quickly. With the aid of this thermal map and the ground truth obtained at the time of flight, the thermal field was analyzed for areas of equal temperature and an isothermal map prepared [Figure 7]. [Analytical techniques are discussed in Chapter IV].

Areas of constant temperature (isotherms) are depicted by a particular color on the isothermal map. The color scheme goes from red, representing the warmest temperature to the orange, yellow, greens, and into the blues that represent the coolest temperatures. Water temperatures corresponding to each isotherm (color) are shown in the legend. This isothermal map has 12 temperature gradient steps ranging from the red or warmest area at the mouth of Oyster Creek

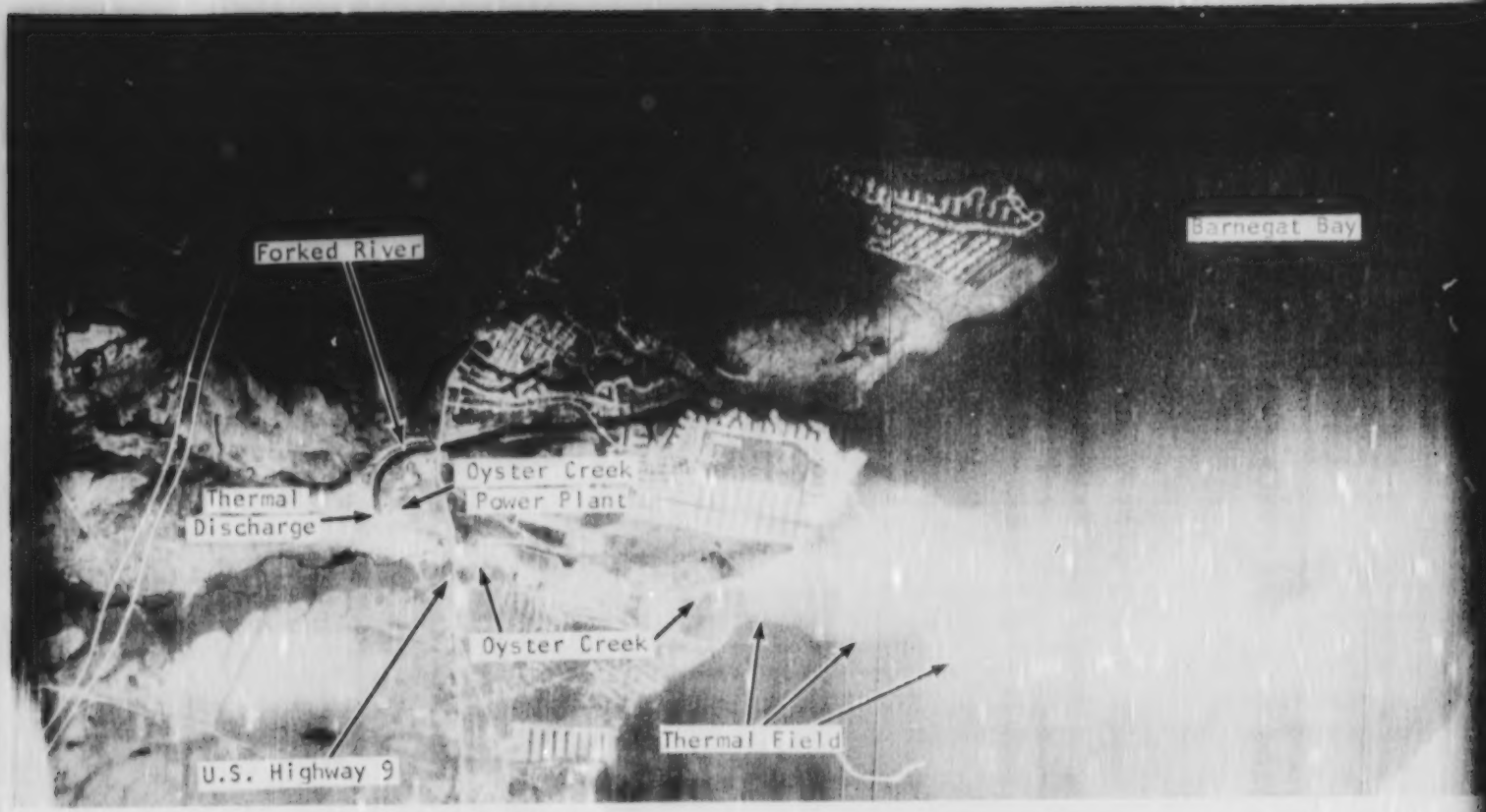

Forked River
Barnegat Bay
Thermal
Discharge
Oyster Creek
Power Plant
Oyster Creek
U.S. Highway 9
Thermal Field

FIGURE 6 Thermal Field, Oyst
Power Plant (High A

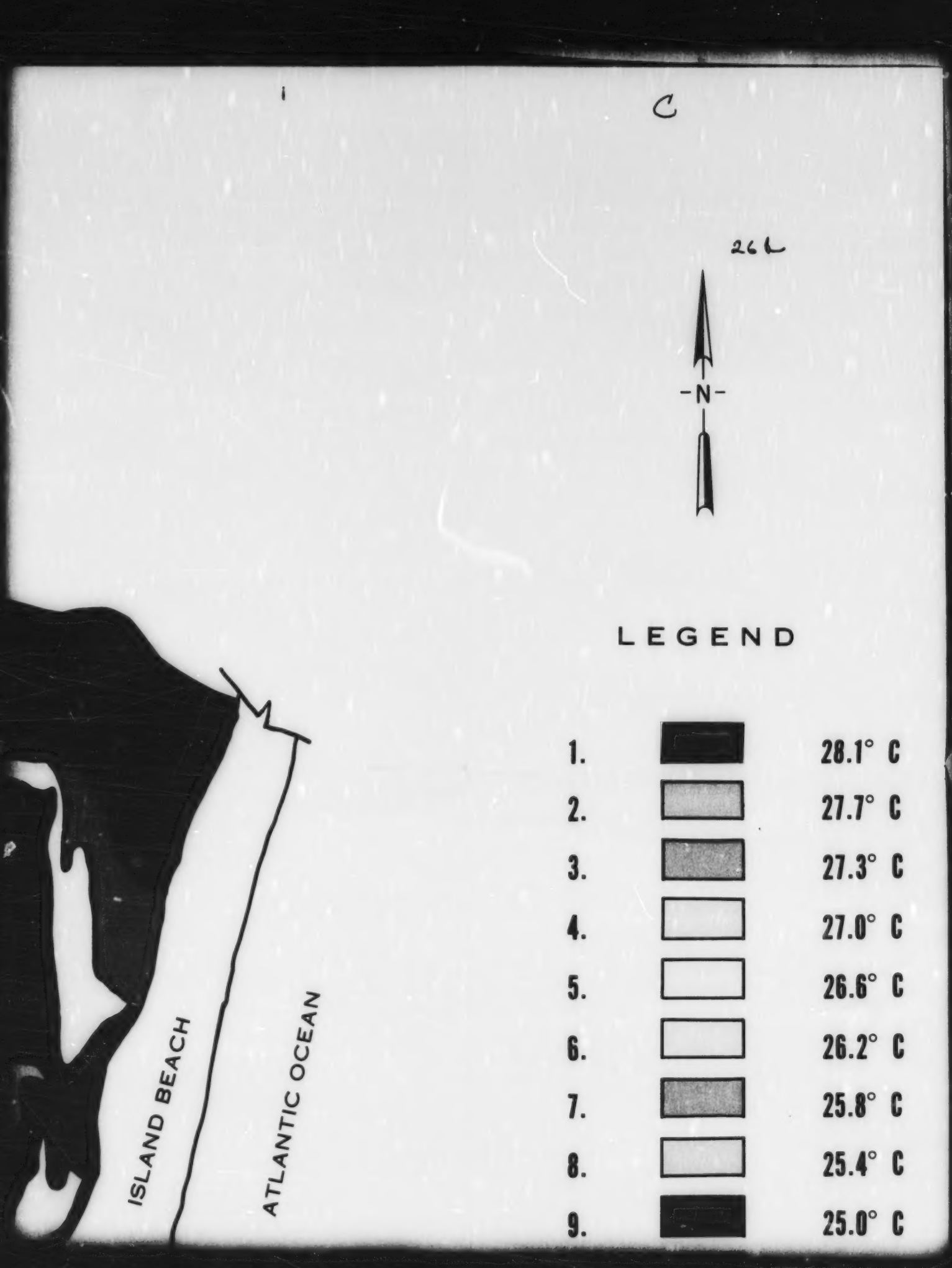
B

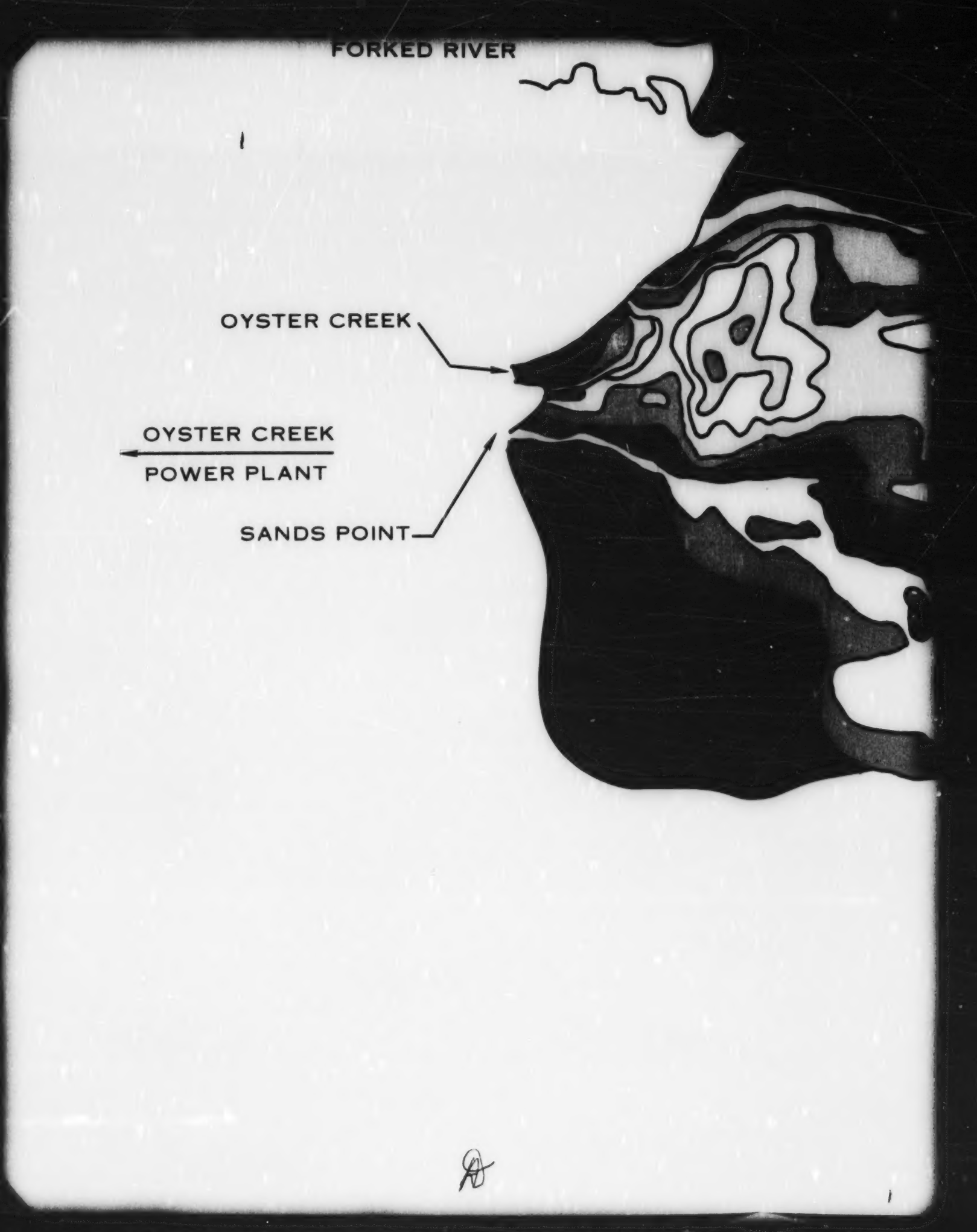
FIGURE 6 Thermal Field, Oyster Creek Power Plant (High Altitude)

A

B

BARNEGAT BAY


N
LEGEND
1. 28.1° C
2. 27.7° C
3. 27.3° C
4. 27.0° C
5. 26.6° C
6. 26.2° C
7. 25.8° C
8. 25.4° C
9. 25.0° C
ISLAND BEACH
ATLANTIC OCEAN


FORKED RIVER
OYSTER CREEK
OYSTER CREEK
POWER PLANT
SANDS POINT

Fig

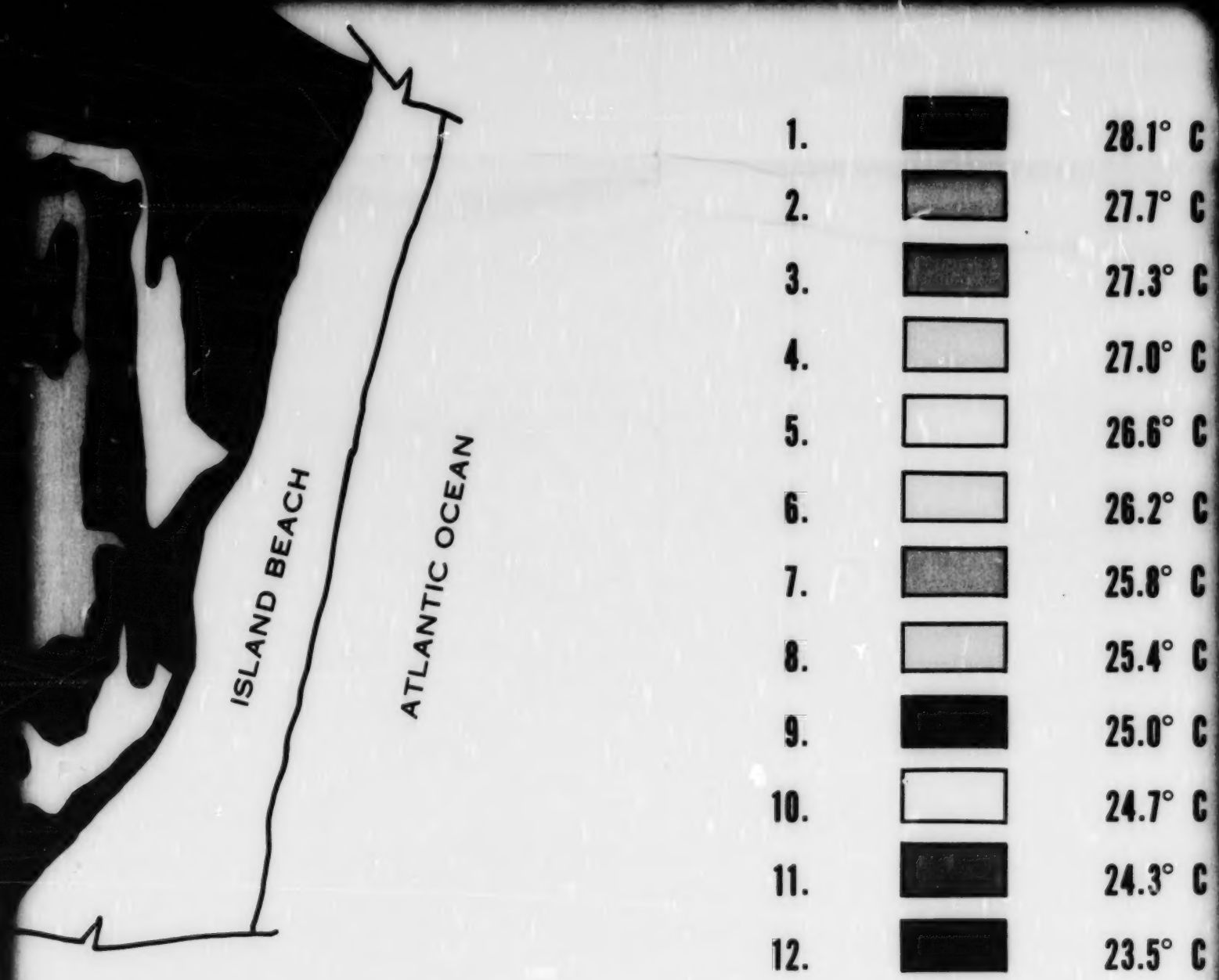


Figure 7. Isothermal Map of the Oyster Creek Thermal Field

(labeled No. 1) with a temperature of 28.1°C (82.5°F) to the significantly cooler blue ambient or background receiving water areas (labeled No. 12) with a temperature of 23.5°C (74.3°F).

Temperature differences between most isotherms in Figure 7 are 0.4°C (0.7°F). This temperature interval is well within the resolution capability of the infrared line scanner, recalling that its noise equivalent temperature is 0.32°C with 100 percent probability of detection. The differences in temperature between steps 3 and 4, 9 and 10, and 11 and 12, are not 0.4°C. This could be due to the fact that the temperature of the water at the particular ground truth sample location (located within 15 cm of the water surface) was slightly different from that of the very thin layer of the surface water. A second possibility is that a slight temperature change occurred during the short time interval between some ground truth measurements and the recording of the infrared image as not all ground measurements could be made simultaneously. The effect is that the particular shade of gray in the film, representing the missing 0.4°C steps, was not present.

The observed thermal pattern [Figure 7] is quite complex. The warmest area is at the mouth of Oyster Creek where the power plant effluent enters the Bay. A warm plume extends from this point eastward across Barnegat Bay. In addition there are three other areas (shown by yellow and green patches) where the water is considerably warmer than ambient receiving water temperatures, the blue areas in the thermal field. It is believed that this spotted effect may be the result of a superposition of internal waves in the Bay and wind currents to create

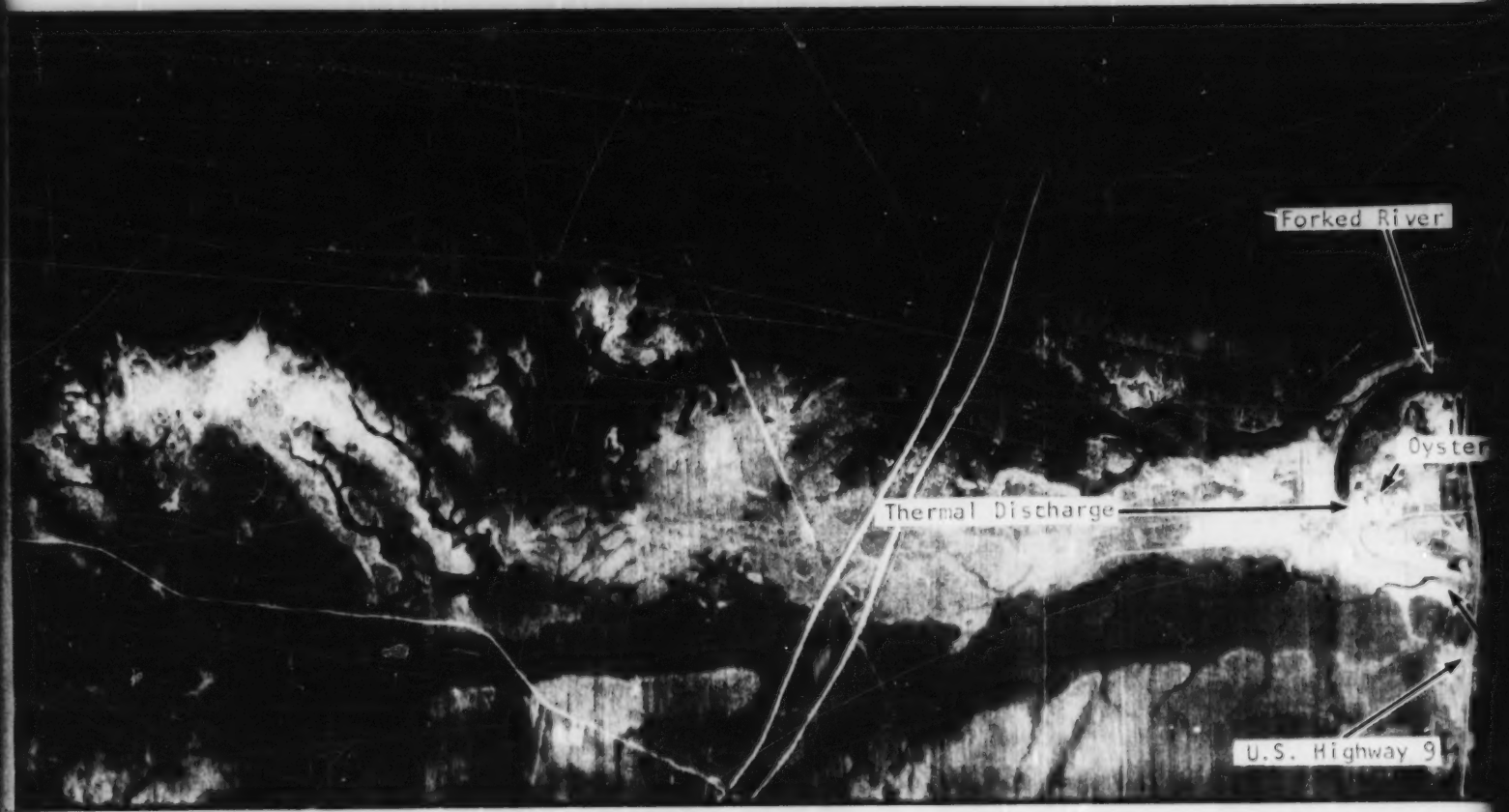
a psuedo upwelling in these areas, thus bringing warmer near-surface waters to the top.

On the day of the flight the prevailing wind was out of the southwest nearly paralleling the west shoreline of Barnegat Bay. Under these conditions, with only a slight offshore wind component, the thermal effects of the power plant effluent extended completely across the Bay to Island Beach. An offshore wind (west or northwest) would be expected to push the plume further offshore while an onshore wind (easterly) would hold the heated water closer to the western shore and dispersing in a southerly direction. Likewise, a north or south wind would tend to hold the plume closer to the western shore.

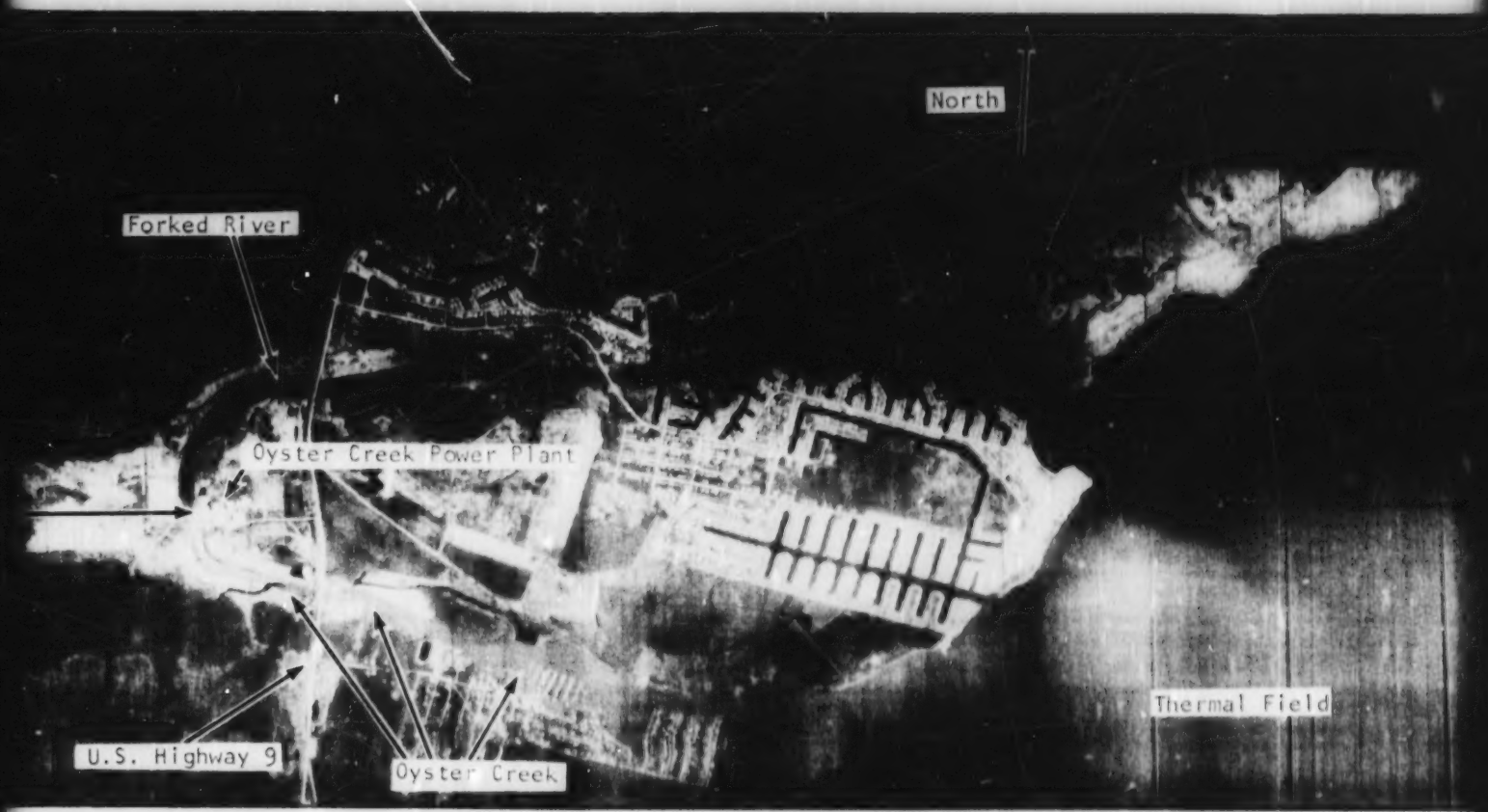
The low streamflow present in Oyster Creek on 13 July would have essentially no effect on the thermal plume. At high runoff stages the creek flow would be expected to exert only minor effects on plume patterns owing to the small stream size.

Tidal conditions in Barnegat Bay were nearly static for several hours before the time of flight. Tidal conditions thus exerted little influence on the observed thermal plume. Owing to the constricting effect of Barnegat Inlet and the low tide range in Barnegat Bay, little translation of the plume location should occur between flood and ebb tide stages.

A thermal map was also obtained by a lower altitude (915 m or 3,000 ft above water level) flight to provide greater detail in the main thermal plume area. A positive print [Figure 8] of the infrared image obtained at this altitude shows a thermal pattern very similar to the higher altitude thermal map [Figure 6]. The time lapse between the



A


North
Forked River
Oyster Creek Power Plant
Thermal Field
U.S. Highway 9
Oyster Creek

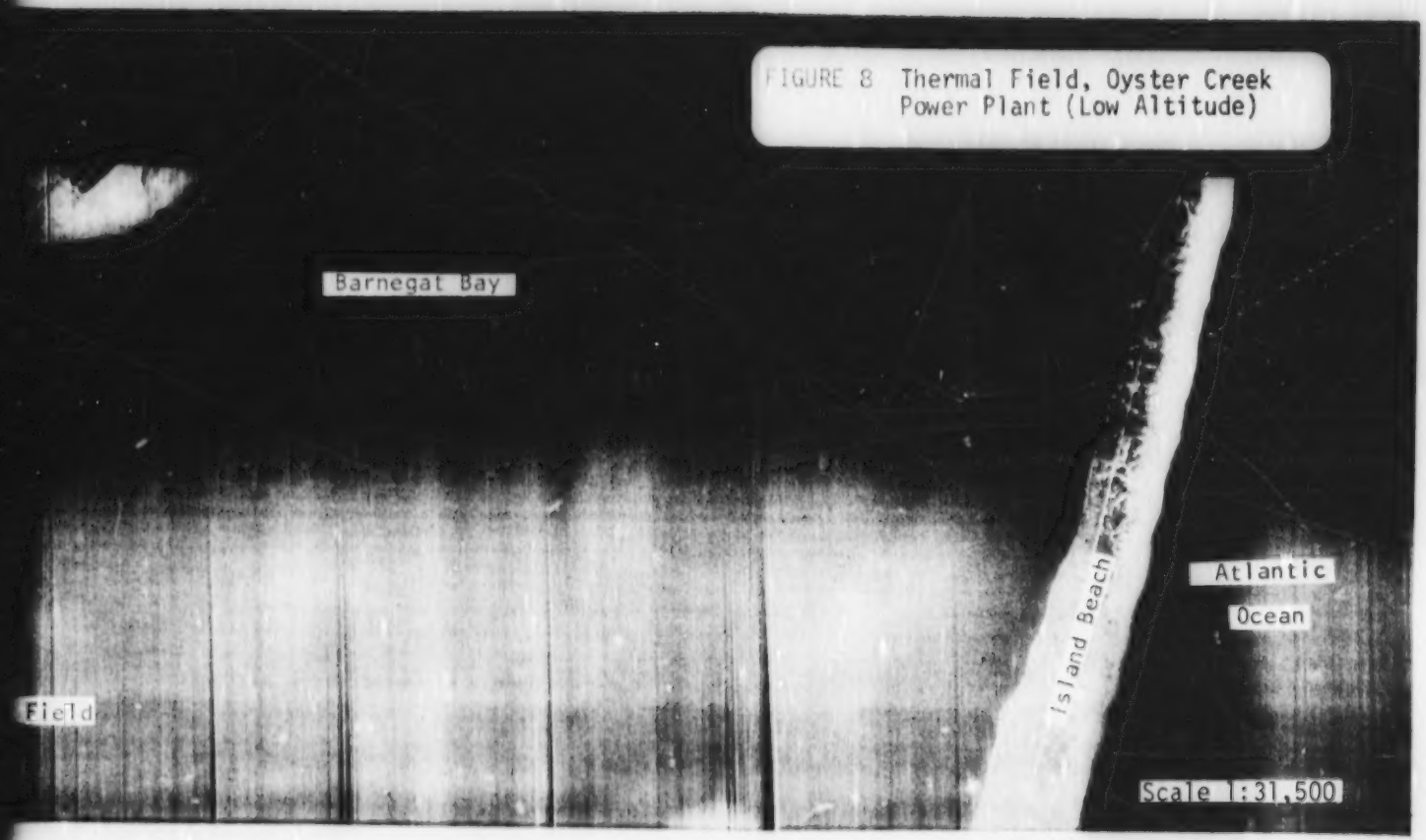
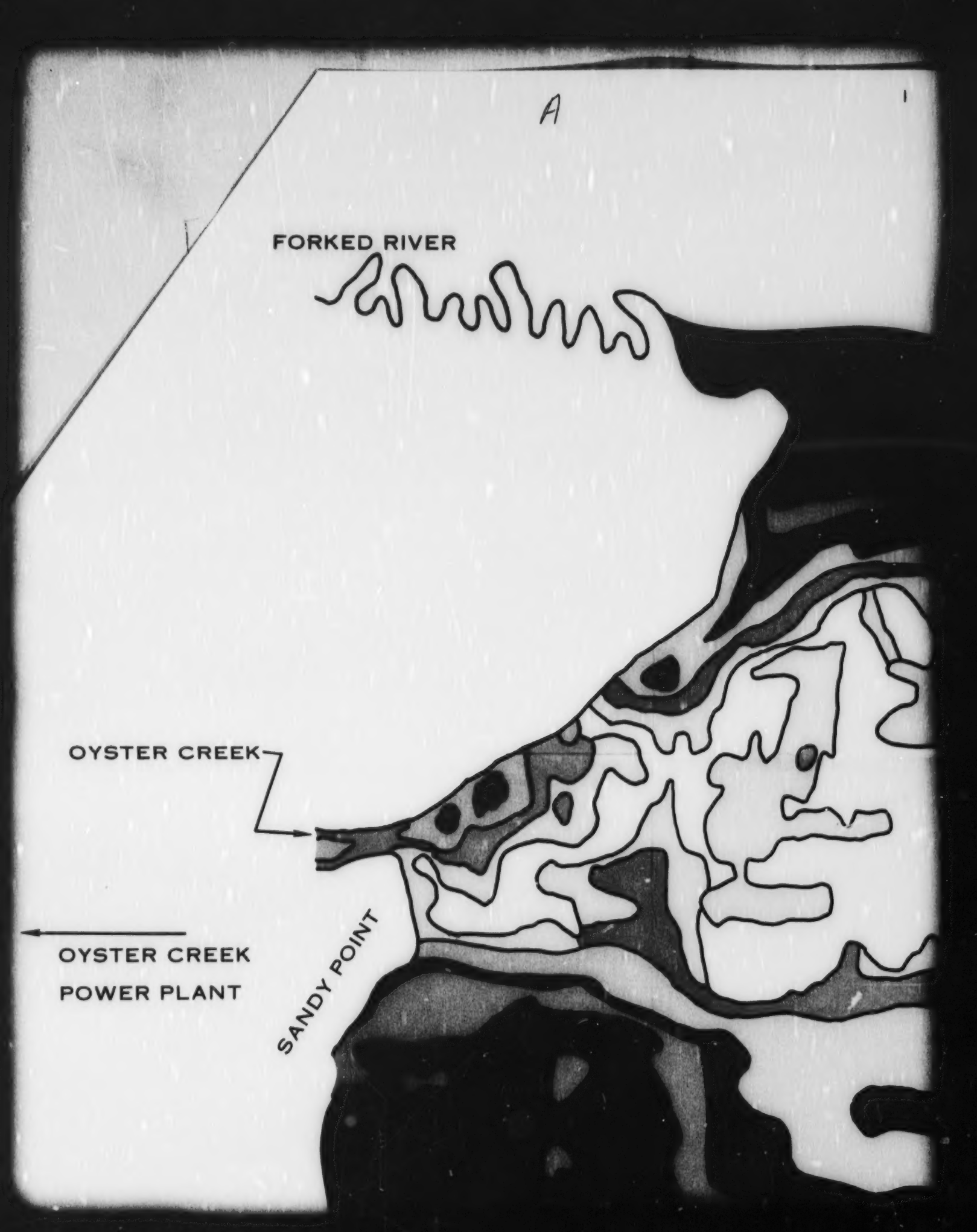


FIGURE 8 Thermal Field, Oyster Creek Power Plant (Low Altitude)

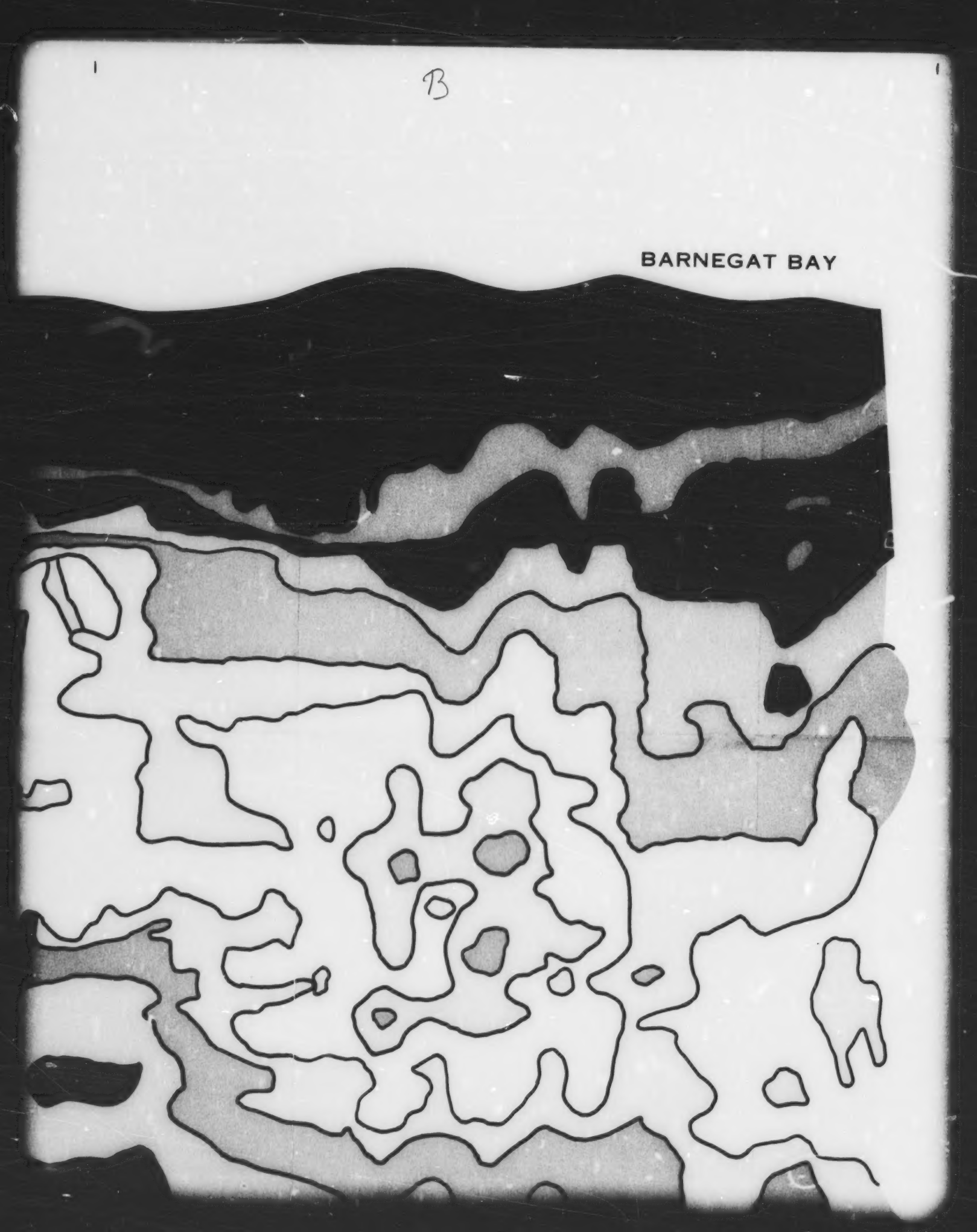
recording of the two images was about 10 minutes. An isothermal map [Figure 9] prepared from the low-altitude infrared image is also comparable to the high-altitude isothermal map [Figure 7]. The warm area (yellow/green) near the top of Figure 9 has the same general shape as the respective warm area in Figure 7 located about one-third the distance between the mouth of Oyster Creek and Island Beach. The warmest waters, near the mouth of Oyster Creek, occupy the same area in both isothermal maps.

In an attempt to determine the cause of the complex thermal field observed, a bottom profile [Figure 10] was plotted for a line extending from the mouth of Oyster Creek to Island Beach (between the two arrows on Figure 7) using water depths obtained from a nautical chart.[9/] Except in the navigational channel at the mouth of Oyster Creek, the waters of Barnegat Bay are less than 2 m (6 ft) deep for a distance of about 800 m (2,600 ft) offshore at the Creek mouth. This shallow water is in contrast to Oyster Creek channel depths of more than 3 m (10 ft) and Bay areas deeper than 4 m (13 ft). The Oyster Creek navigation channel has a constructed depth of 2 m (6 ft). The rise in the bottom of the Oyster Creek channel coupled with the spreading of water out of the channel into shallower Bay areas and the buoyancy of the warm water would tend to deflect the outflow from Oyster Creek to the surface as depicted in Figure 10. Internal Bay currents and wind currents could then distribute this warm water in the general area beyond the rise to form the observed thermal pattern.

The isothermal maps indicate that the warm water within the thermal

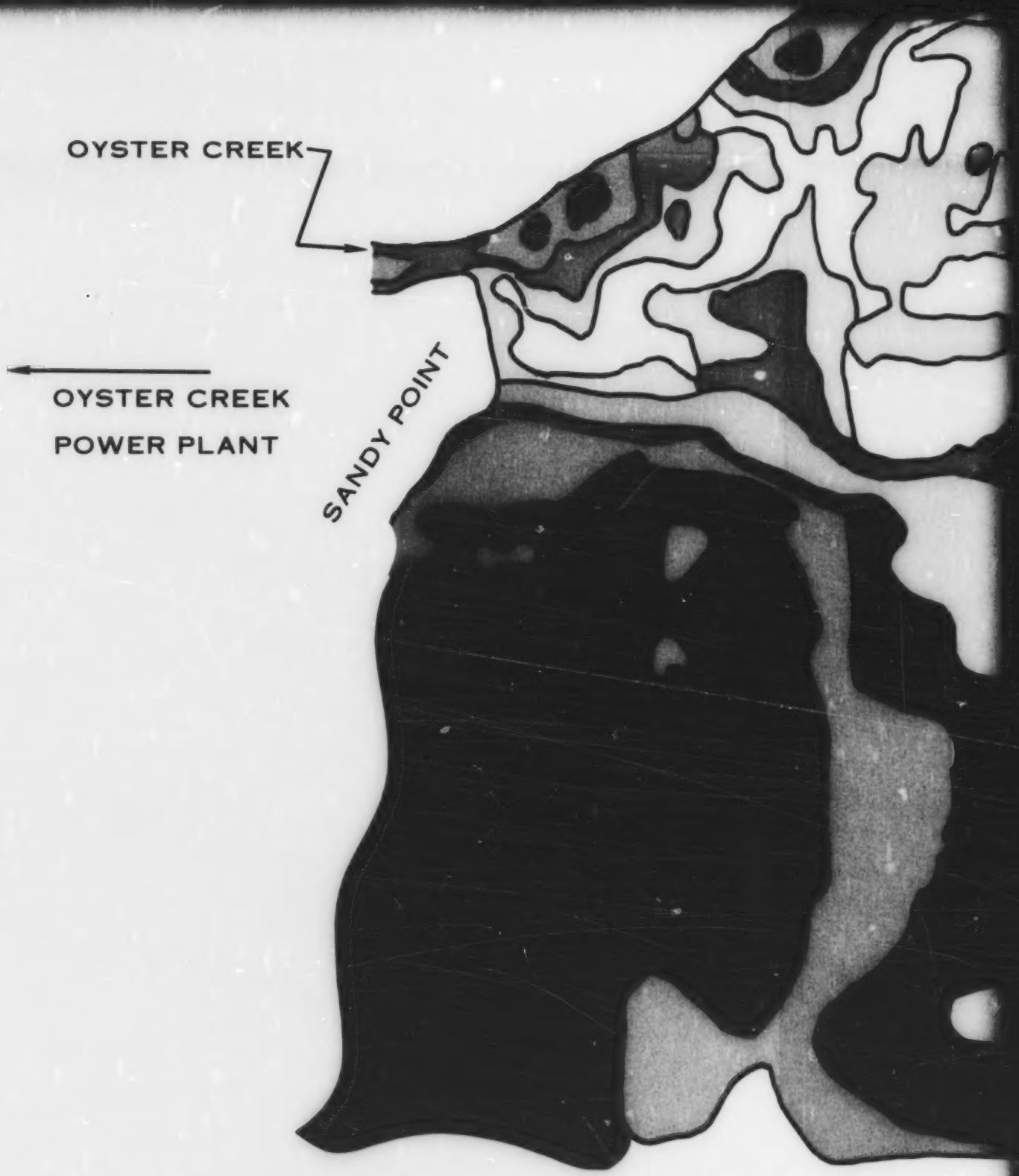

A
FORKED RIVER
OYSTER CREEK
OYSTER CREEK
POWER PLANT
SANDY POINT

B

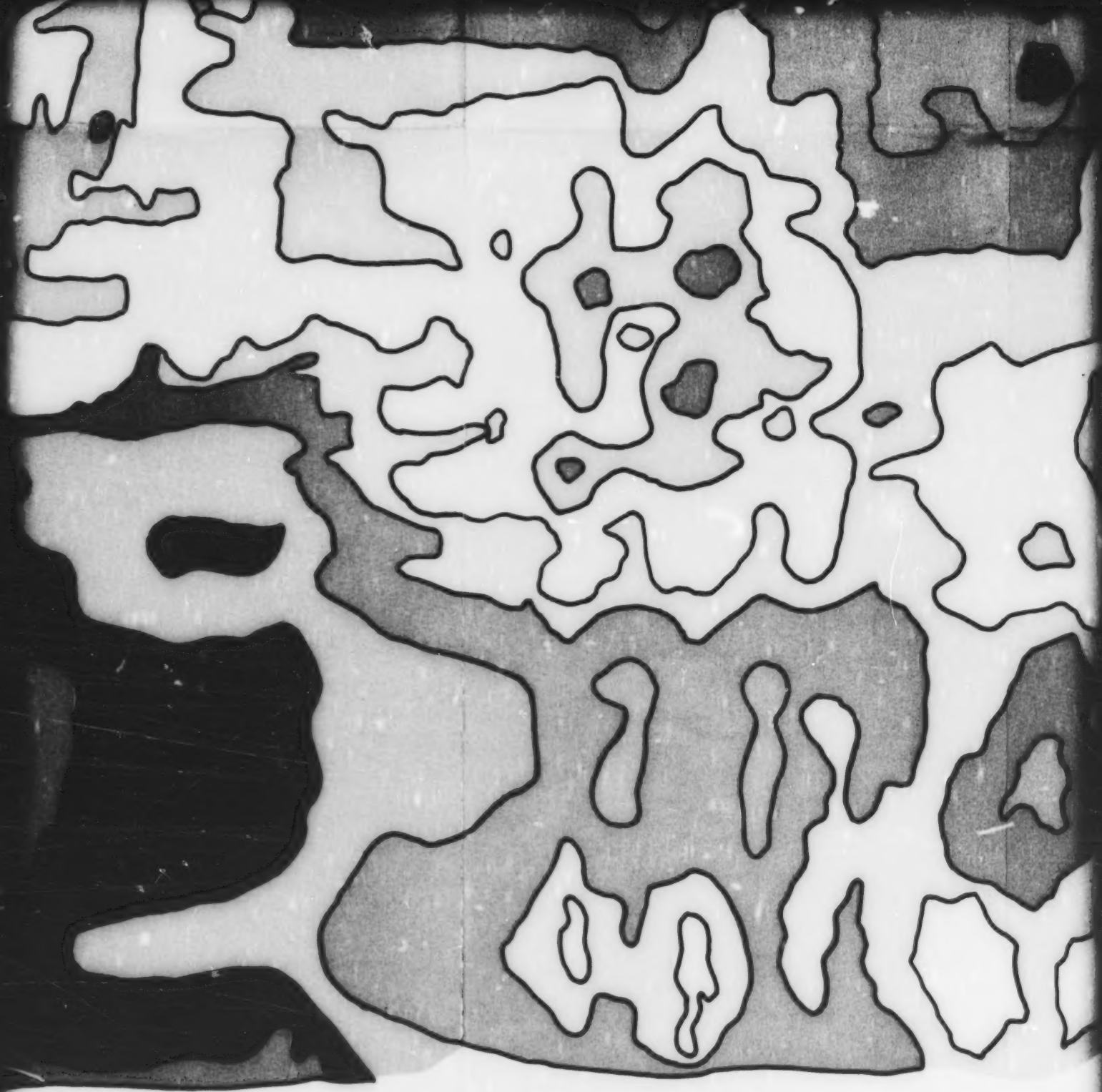


LEGEND

1.		28.1° C
2.		27.7° C
3.		27.3° C
4.		26.6° C
5.		26.2° C
6.		25.8° C
7.		25.4° C
8.		25.0° C
9.		24.7° C
10.		24.3° C



D



E

1.		28.1° C
2.		27.7° C
3.		27.3° C
4.		26.6° C
5.		26.2° C
6.		25.8° C
7.		25.4° C
8.		25.0° C
9.		24.7° C
10.		24.3° C
11.		23.5° C

Figure 9. Isothermal Map of the Oyster Creek Thermal Discharge

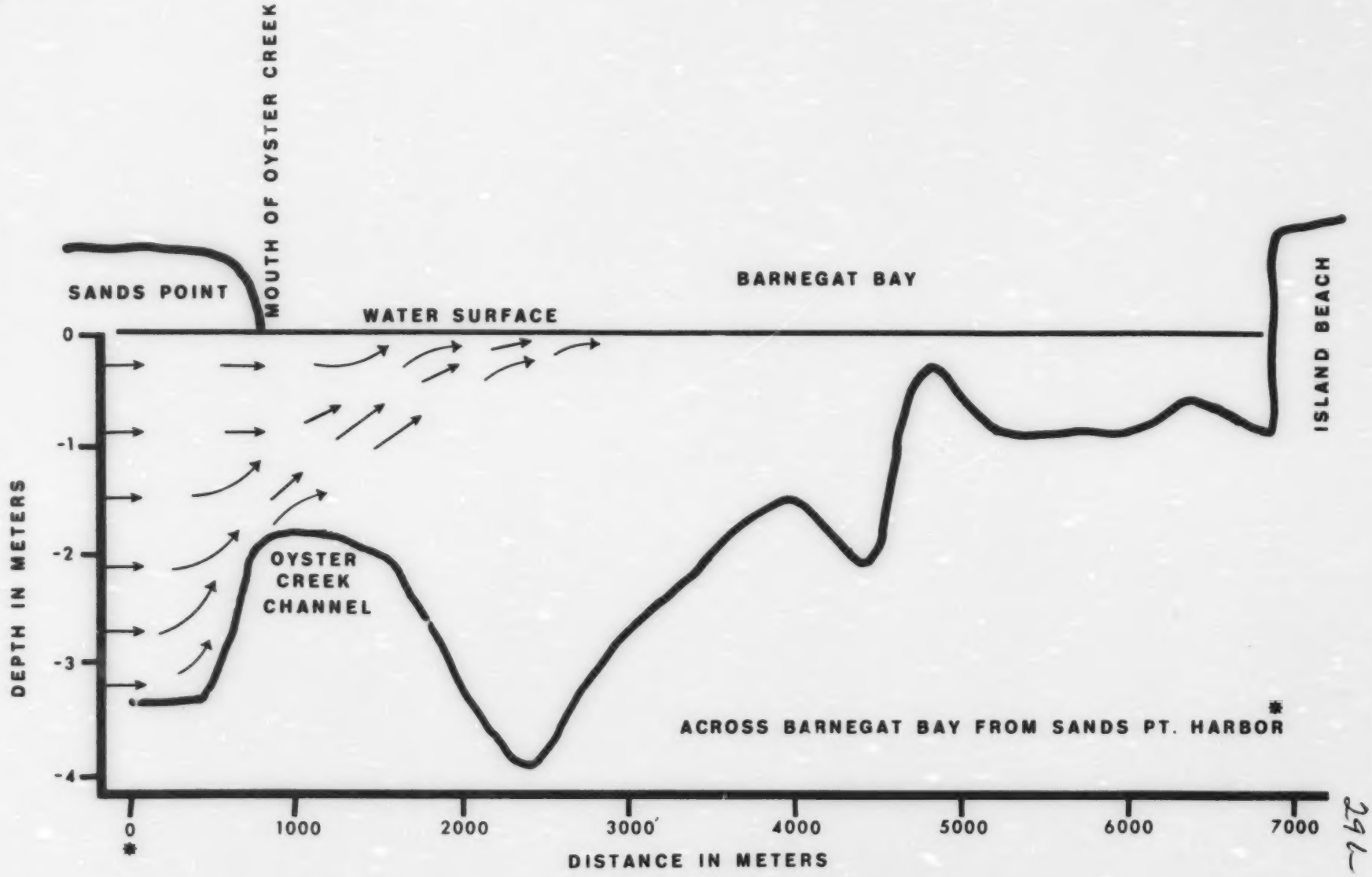


Figure 10. Elevation Profile of Barnegat Bay

plume, at the surface level, was not entering the Forked River which the Oyster Creek power plant uses for its source of cooling water.

The various shades of gray observed in Oyster Creek from the power plant's discharge to its mouth [Figure 8] indicate that the Creek water is very slowly cooling (by heat transfer to the atmosphere and dilution) as its progresses toward Barnegat Bay. Around the bend from the discharge, a small creek (visible by the black or colder water) is seen emptying into Oyster Creek. A temperature profile [Figure 11] of the surface waters in Oyster Creek from the US 9 Bridge to its mouth was prepared from the thermal map. It is quite different in comparison to temperatures measured in the Creek by EPA in October 1970 (prior to plant operation) and March 1971 (during the initial phase of plant operation).[10/] This difference reflects the combined effects of higher intake water temperatures in July relative to March and October and a higher heat load and cooling water discharge under full-scale operations.

Comparison of Observed and Allowable Water Temperatures

Applicable water quality guidelines for New Jersey coastal waters [Section III] propose that no more than 25 percent of the vertical cross-sectional area (a vertical plane passed through the water at a particular point) of the Bay water may exceed 0.8°C (1.5°F) over ambient (background) temperature in the summer months of June through August, and 2.2°C (4.0°F) over ambient the remainder of the year.[3/] No heat may be added, except in designated mixing zones, which would cause water temperatures to exceed 29.4°C (85°F). In addition no more than two-thirds of the

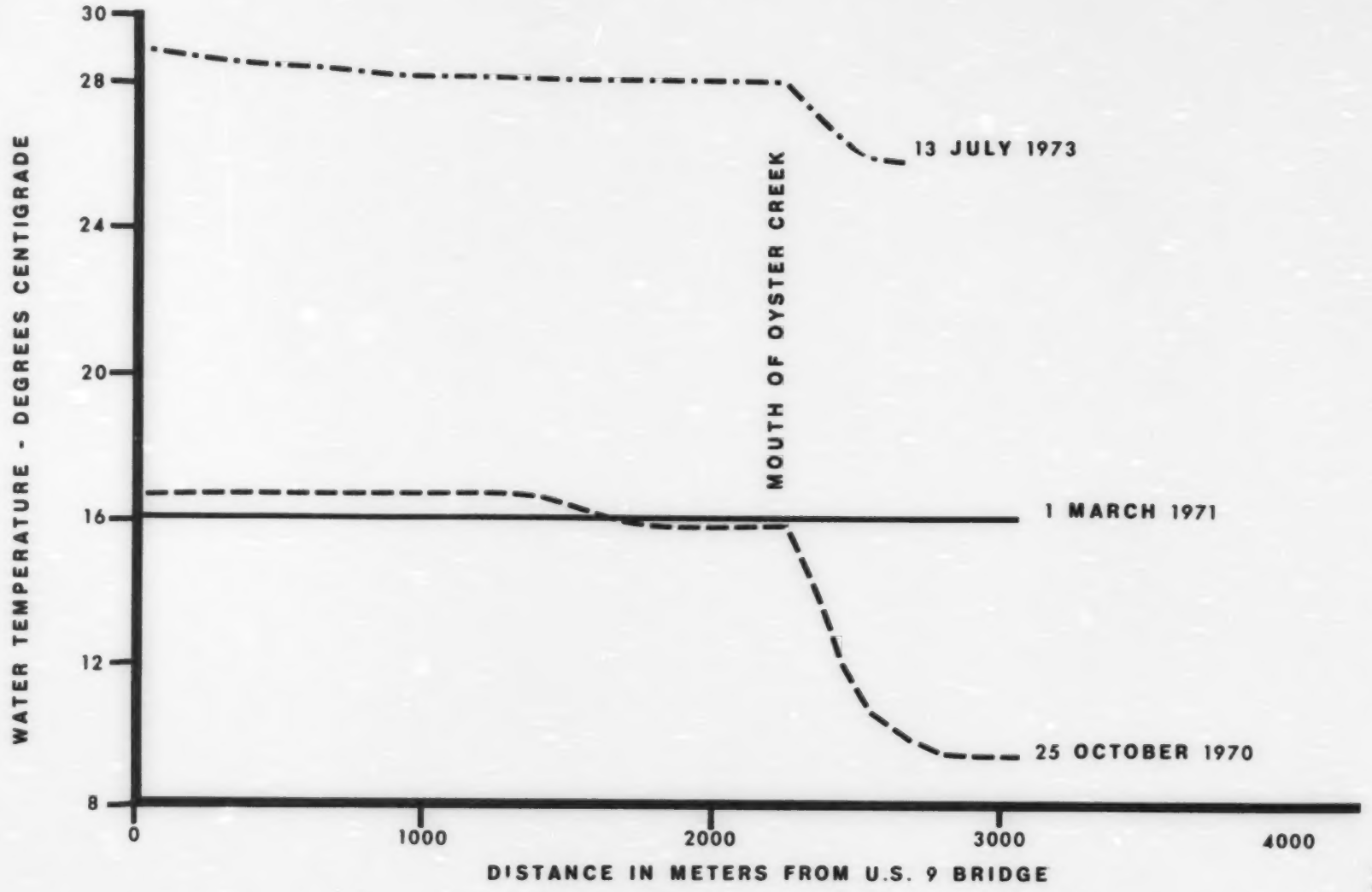


Figure 11. Temperature Profile of Oys er Creek

surface water in the vertical cross section, may be heated to the temperature limits given above.

Recalling that the airborne infrared line scanner can image only the surface layer of a body of water, only that portion of the thermal criteria relating to surface temperatures can be evaluated for Barnegat Bay. The thermal field in Barnegat Bay extended from Oyster Creek (the source) to Island Beach, the full width of the Bay. Isotherm No. 9 in Figure 7, with a temperature more than 0.8°C above ambient (Isotherm No. 12), extends completely across Barnegat Bay from the mouth of Oyster Creek and covers a surface area of more than 10 sq km (4 sq mi). This is not within the limit of the "two-thirds surface" guideline. None of the areas in Barnegat Bay exceeded the 29.4°C (85°F) maximum limit.

The surface temperature in Oyster Creek, which has not been designated as a "mixing zone", exceeded the 0.8°C criterion based upon the surface temperature of the ambient water in Barnegat Bay. Since nearly the entire flow in Oyster Creek was cooling water, it is quite probable that the entire volume of water in the creek had a temperature much greater than 0.8°C over ambient. This would not be within the "25 percent" guideline discussed above. None of the Creek water below the US Hwy 9 Bridge exceeded the 29.5°C criterion. However upstream of this bridge and the cool creek, Oyster Creek exceeded the allowable limit. The surface temperature of the water near the discharge was 31°C (88°F), dropping to 29.0°C (84°F) immediately above the US HWY 9 Bridge. Approximately 310 m (1,020 ft) of Oyster Creek from the discharge downstream, exceeded the 29.4°C maximum limit. This applies only to

the water surface due to the opacity of water in the intermediate infrared band.

GREAT EGG HARBOR BAY

The B. L. England Generating Station discharges cooling water to the western end of Great Egg Harbor Bay [Figure 3]. The Bay was investigated with infrared sensors on 13 July 1973.

Environmental Conditions at Time of Flight

Weather conditions at Atlantic City (about 15 km or 10 mi northeast) during the survey are listed in Table V-2 in the previous section on Barnegat Bay.

Predicted tide conditions for Great Egg Harbor Inlet and a point in Great Egg Harbor Bay near the cooling water discharge location are summarized in Table V-3. Actual tide levels were not measured but wind conditions and streamflow in the Tuckahoe and Great Egg Harbor Rivers would indicate that normal tide conditions existed.

TABLE V-3

PREDICTED TIDE CONDITIONS - GREAT EGG HARBOR BAY[6/]
13 JULY 1973

Location	Tide (EDT)	Tide Level		Tide
		Meters	Feet	
Great Egg Harbor Inlet	0106	0.1	0.3	Low Low
	0722	1.0	3.2	Low High
	1306	0.2	0.5	High Low
	1944	1.3	4.4	High High
Great Egg Harbor Bay	0208	0.1	0.3	Low Low
	0754	0.9	3.0	Low High
	1408	0.2	0.5	High Low
	2016	1.3	4.2	High High

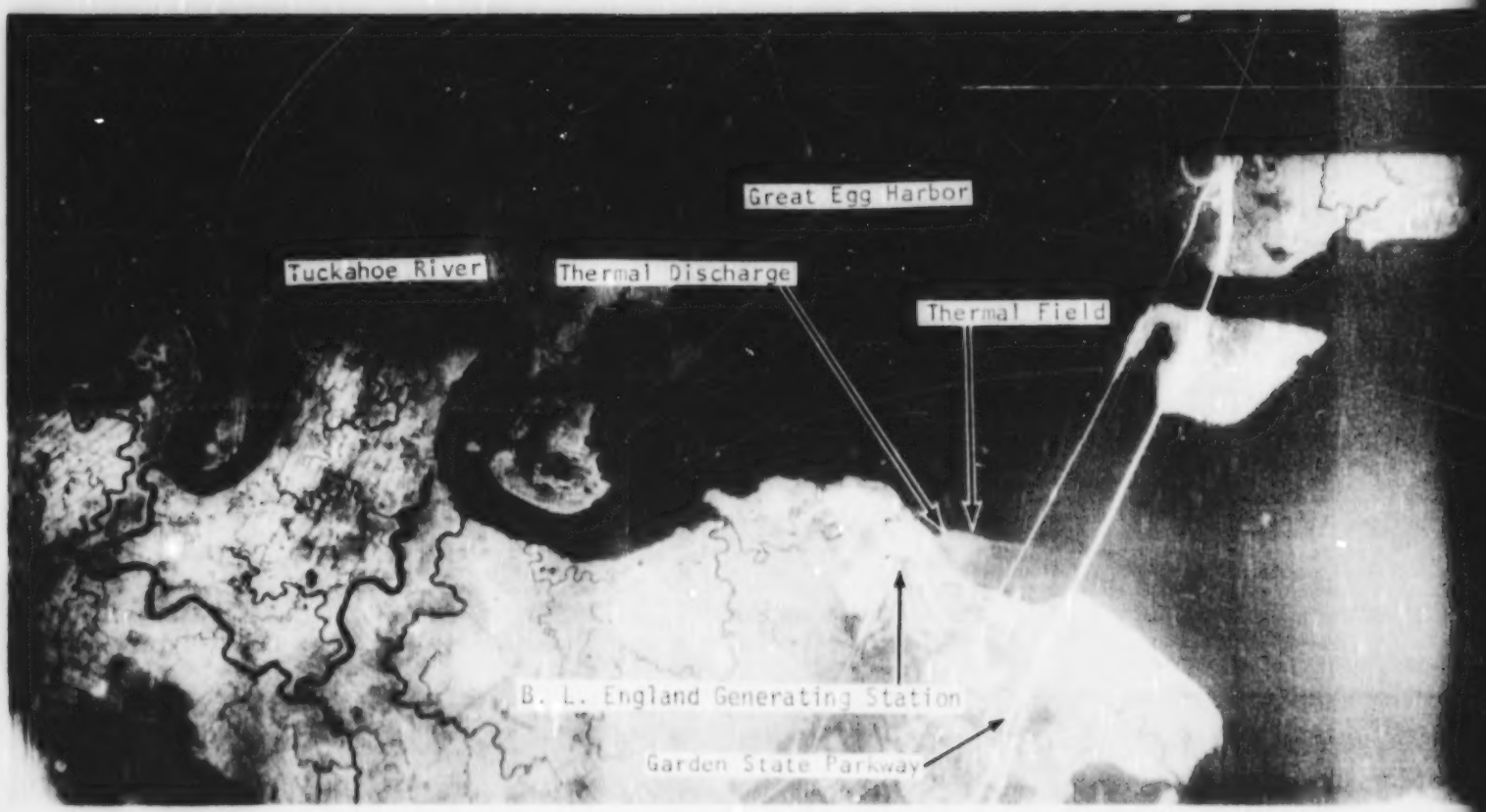
Note that, in contrast to Barnegat Bay, tide levels in Great Egg Harbor Bay very closely approximate tides at the Bay inlet except for a time lag.

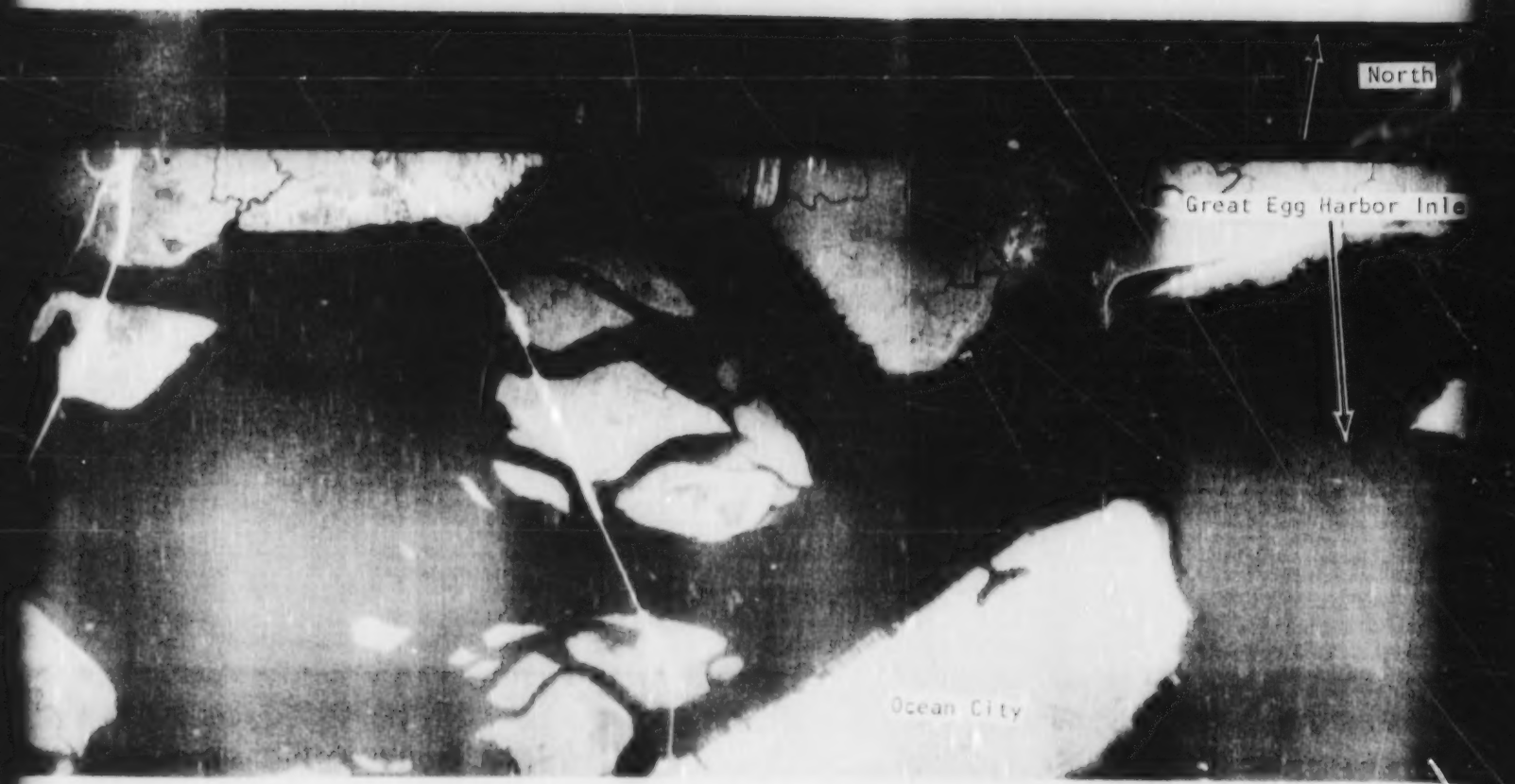
At the time of flight, the tide was in ebb phase at both locations with the total water level drop (relative to the previous high tide) of 0.8 m (2.7 ft) and 0.7 m (2.5 ft) for the Inlet and Bay, respectively. Tide currents would thus have been at near peak downstream velocities during the previous several hours.

Freshwater inflow to the upper end of Great Egg Harbor Bay from the Tuckahoe and Great Egg Harbor Rivers was estimated by the U.S. Geological Survey to total 17.6 m^3/sec (620 cfs).[8/] Based on the rate of change of the volume of the tidal prism in the Bay, the average flow rate through Great Egg Harbor Inlet was estimated to be about 850 m^3/sec (30,000 cfs) for the ebb tide phase during the time of flight. The freshwater inflow would thus be expected to exert only minor influences on water temperature, salinity, and tidal current velocities in the Bay. These effects would be limited to the upper end of the Bay. During high runoff conditions in the rivers, more significant effects on the Bay would result.

Thermal Plume Characteristics

A thermal map of Great Egg Harbor Bay, in the form of a positive print of the infrared imagery recorded at an altitude of 915 m (3,000 ft), is shown in Figure 12. Recalling that cool areas are dark and warm water areas are light, the thermal plume resulting from the power plant cooling water discharge is clearly visible to the west of the parallel bridges in the left-hand portion of the image.


Great Egg Harbor
Tuckahoe River
Thermal Discharge
Thermal Field
B. L. England Generating Station
Garden State Parkway


North
Great Egg Harbor Inle
Ocean City

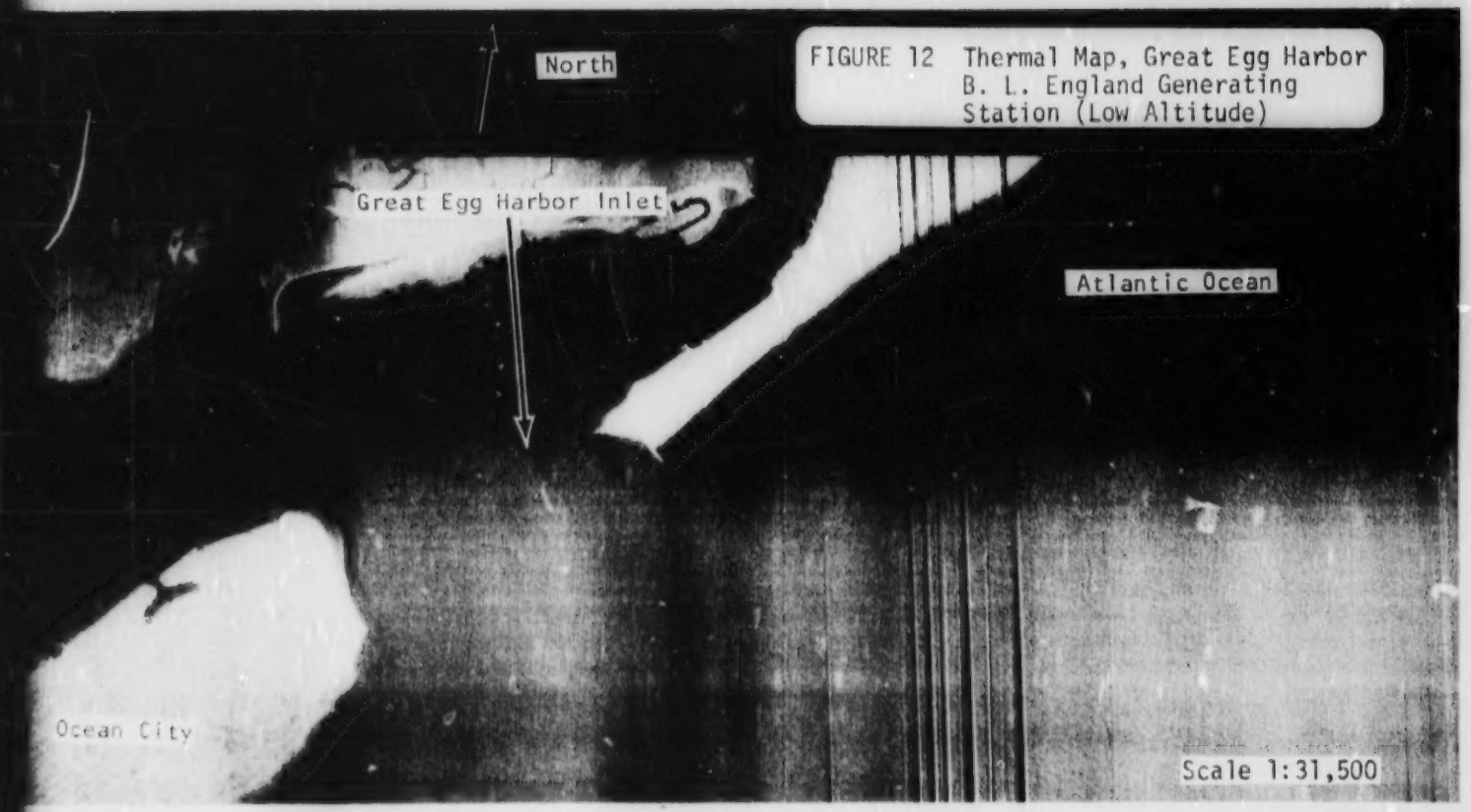
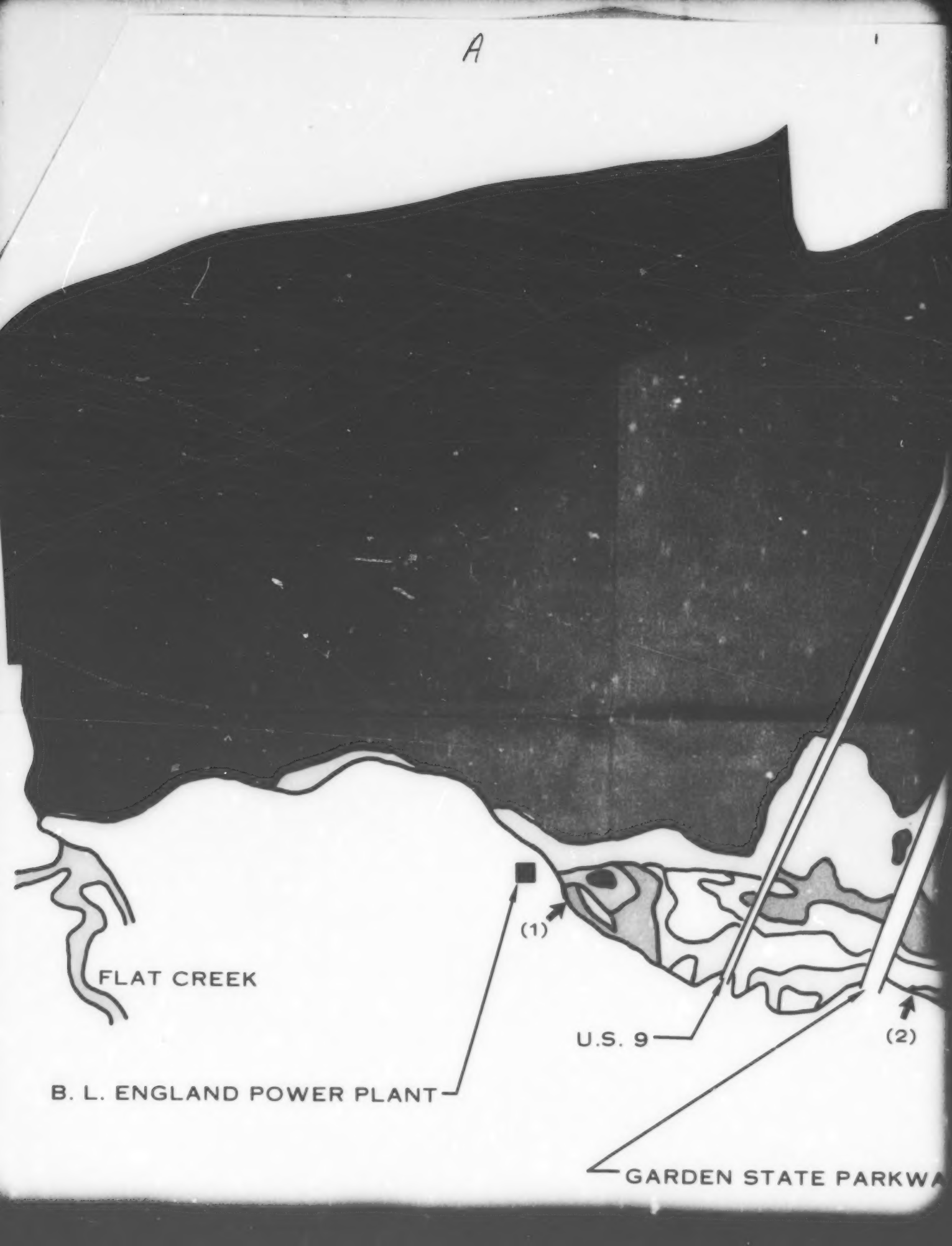


FIGURE 12 Thermal Map, Great Egg Harbor
B. L. England Generating
Station (Low Altitude)

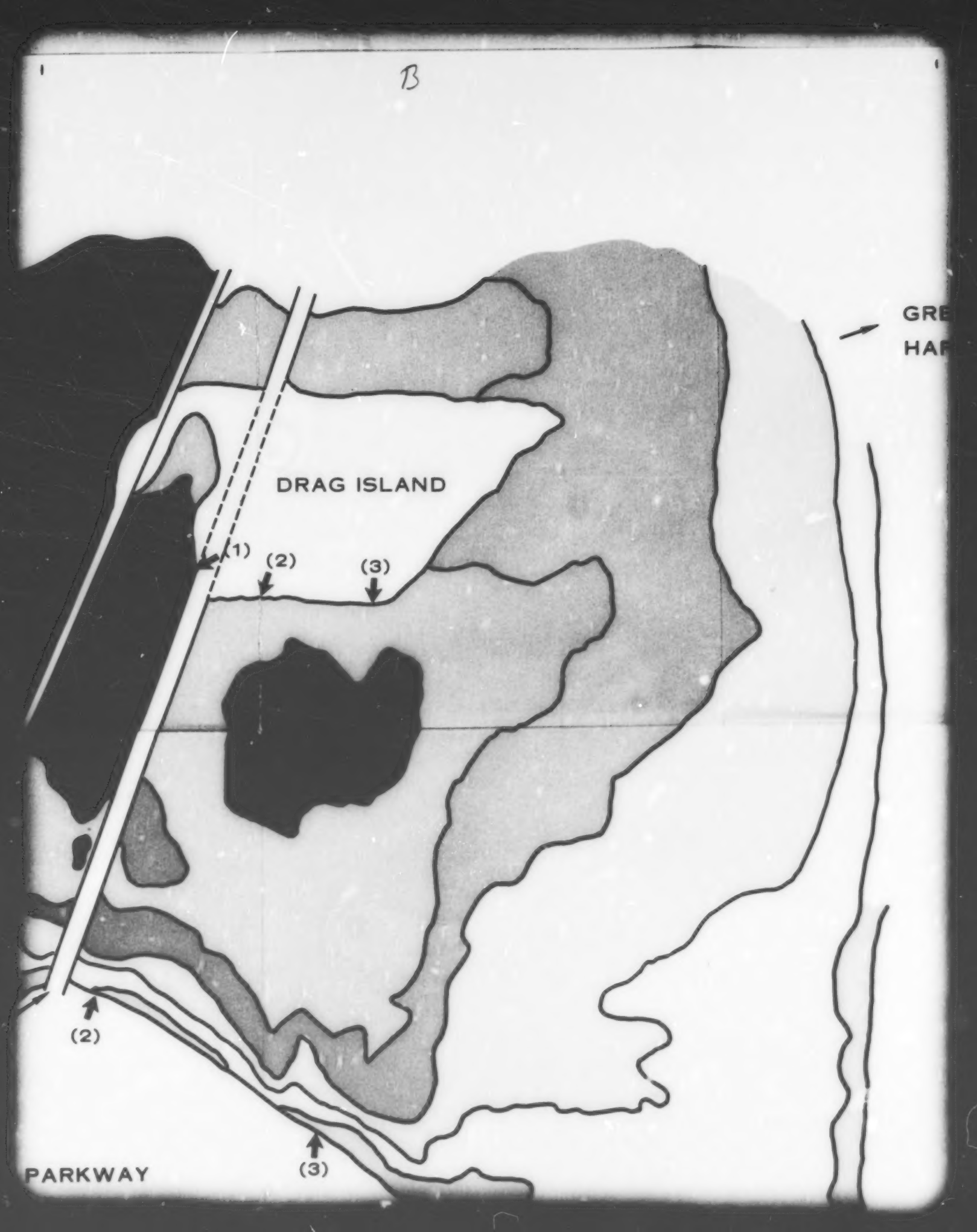
Using the Image Analyzer, an isothermal map [Figure 13] was prepared for the area covering about the central one-fourth of Figure 12, the area encompassing most of the thermal plume. The isothermal map shows that the thermal plume moves along shore under the parallel bridges in an easterly direction and gradually cools. As the plume reaches the entrance to Peck Bay at Golders Point, it deflects in a northerly or counter clockwise direction and moves toward Great Egg Harbor Inlet. This pattern of plume movement reflects the combined effects of tidal currents, wind currents, and advective freshwater inflows. To the west of the entrance to Peck Bay tidal currents during the ebb phase have a generally easterly movement. A measurement of surface water movement made at the time of flight showed water at a point 60 m (200 ft) east of the power plant discharge was moving parallel to shore in an easterly direction at a velocity of 0.3 m/sec (1.0 fps). Freshwater inflows reinforce the easterly movement during ebb tide. Prevailing winds out of the southwest would also aid easterly movement. In contrast, tide flows move out of Peck Bay in a northerly direction during ebb phases. Tidal currents from Peck Bay were thus the probable cause of the observed northward deflection of the plume.

As in the case of the Barnegat Bay isothermal maps, the color scheme for Figure 13 varies from red for the warmest temperatures to blue for the coolest. Water temperatures corresponding to each isotherm (color) are shown in the legend. The warmest temperature observed was 29.4°C (85°F) while background water temperatures were 22.8°C (73°F). Most of the area of the plume was about 26.5° to 27°C (79.7° to 80.5°F) (Isotherm Nos. 5 and 6).

A

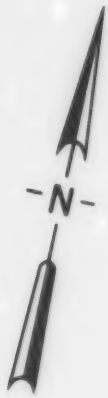

FLAT CREEK
(1)
U.S. 9
(2)
B. L. ENGLAND POWER PLANT
GARDEN STATE PARKWA

B



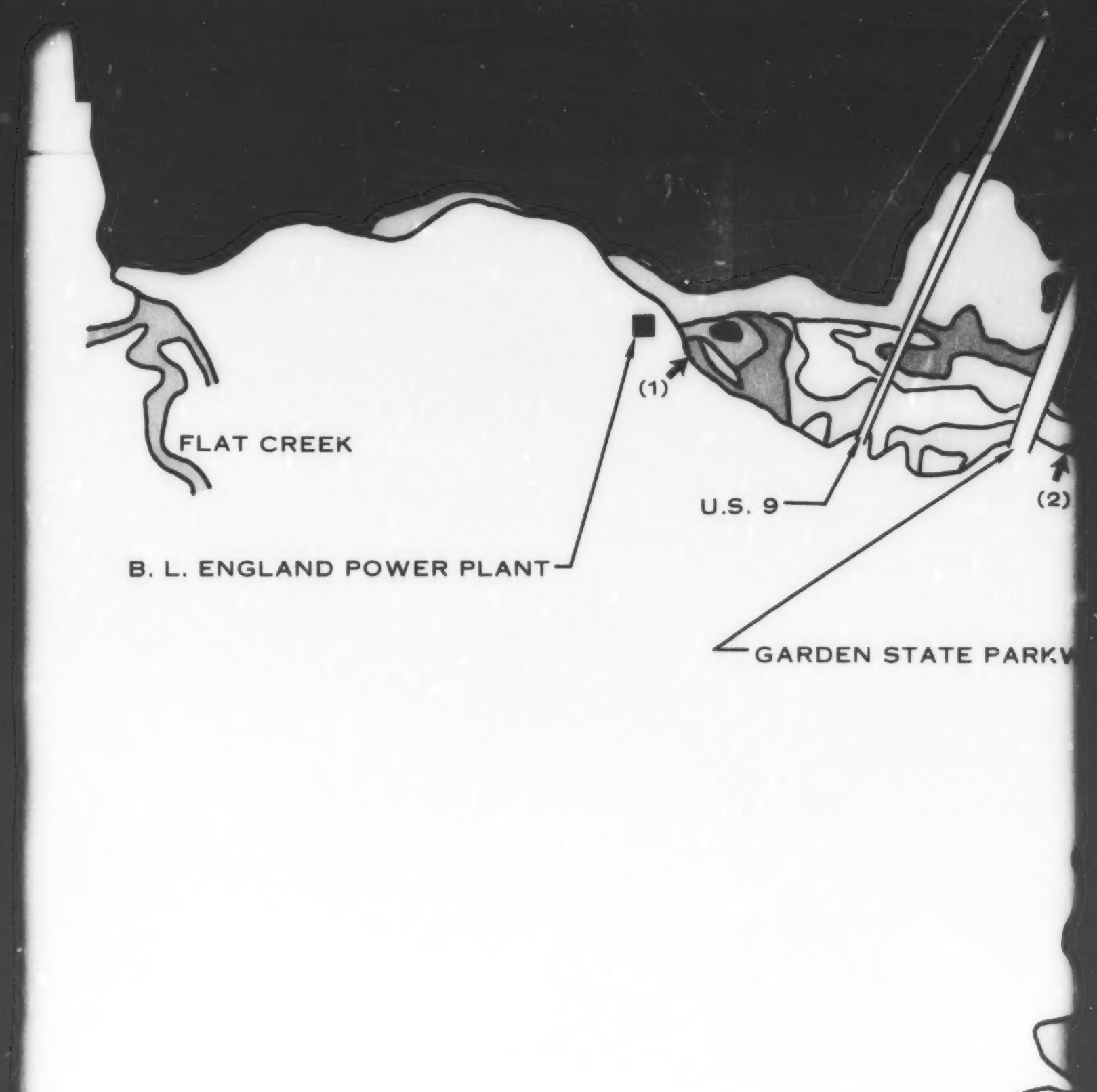
C

34a



LEGEND

1.		29.5° C
2.		28.5° C
3.		28.0° C
4.		27.5° C
5.		27.0° C
6.		26.5° C
7.		26.0° C
8.		25.5° C
9.		23.5° C


FLAT CREEK
(1)
U.S. 9
(2)
B. L. ENGLAND POWER PLANT
GARDEN STATE PARKW

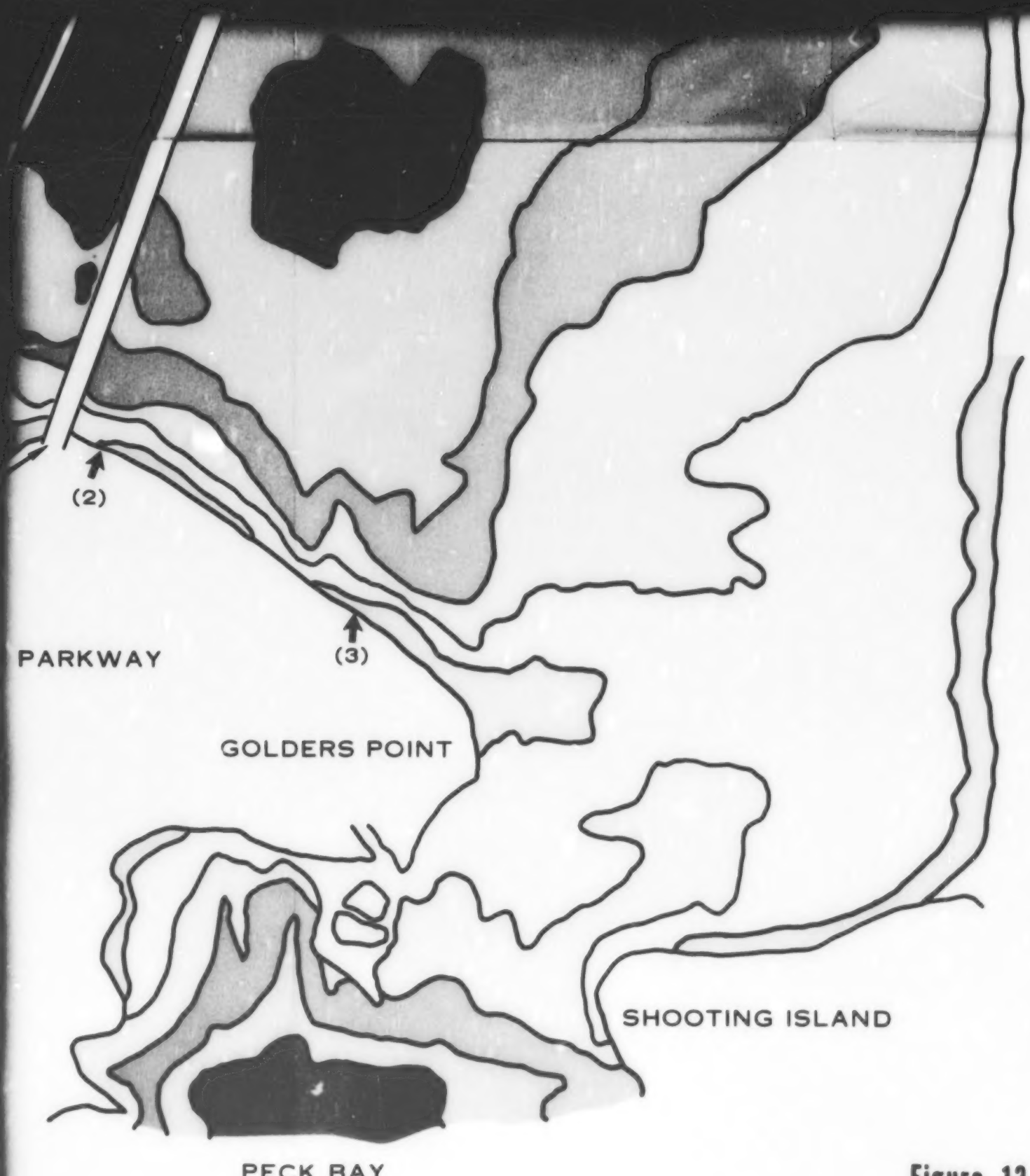


Figure 13 Iso

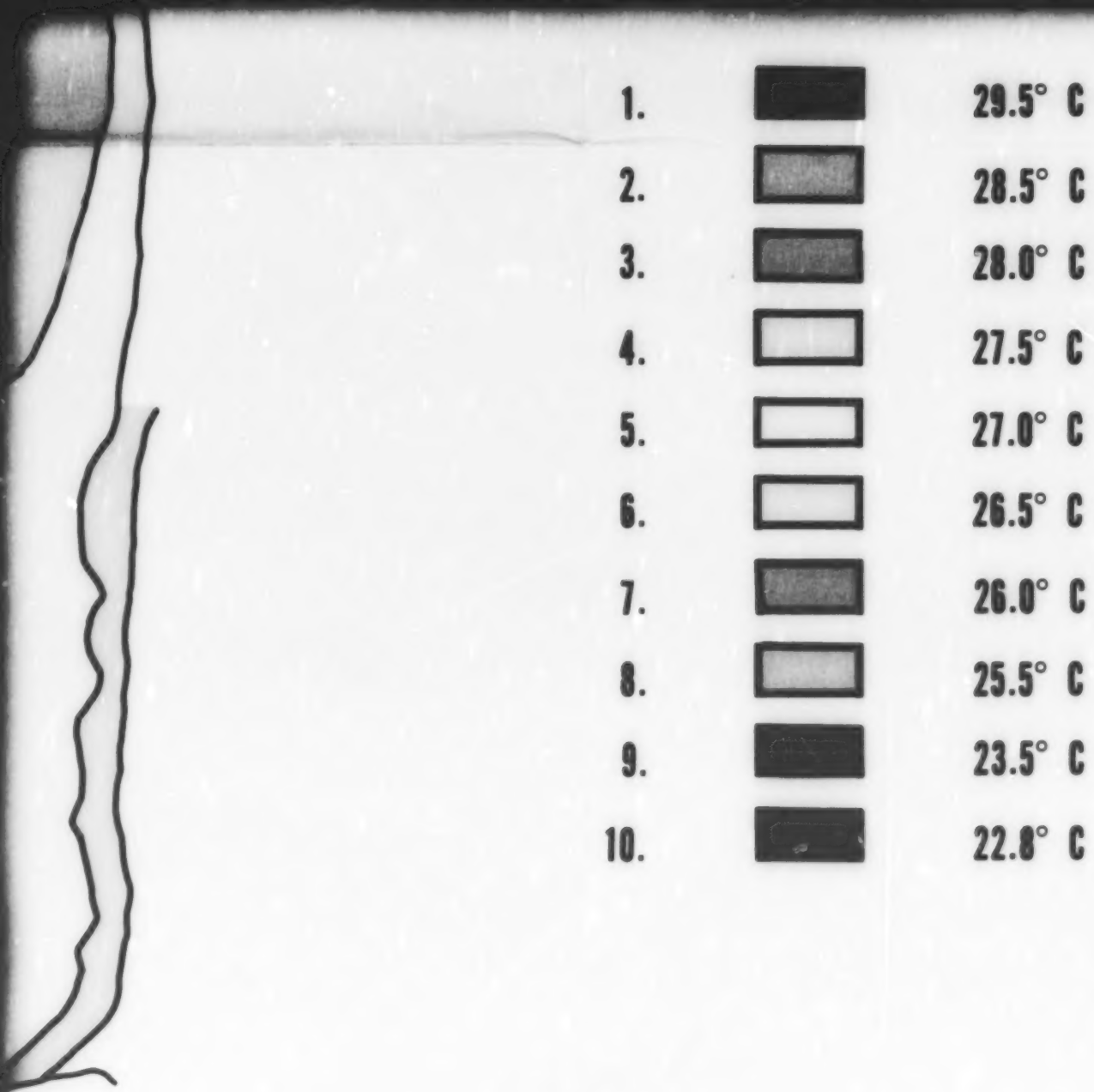


Figure 13 Isothermal Map of the B. L. England Power Plant Thermal Field

It can be noted from the legend [Figure 13] that the temperature differentials between isotherms are 0.5°C except between numbers 1 and 2 and numbers 8 and 9. As discussed before for Barnegat Bay, slight water temperature differentials between surface films and the near surface measurements made on site or slight time lags between ground truth measurements and recording of infrared imagery might have contributed to the missing isotherms.

A high-altitude thermal map [Figure 14] was prepared from infrared imagery recorded at an altitude of 1,830 m (6,000 ft). An isothermal map [Figure 15] was also prepared. These two high-altitude observations defined thermal characteristics of the plume similar to the low-altitude observations. Along shore under the parallel bridges, the thermal plume was the same for both low and high level maps. Thermal patterns in Figure 15 are slightly different, however, in comparison to Figure 13 for areas in the center and right portions of Figure 14 as well as to the east of the bridges. These differences may be attributable to two factors: 1) the aircraft altitude was doubled with resultant effects on the spatial resolution (unit cell size) recording capability of the IRLS on board the aircraft and 2) the time lag of 10 to 12 minutes between the recording of the low- and high-altitude thermal maps would allow some minor changes in the plume position to occur.

Comparison of Observed and Allowable Water Temperatures

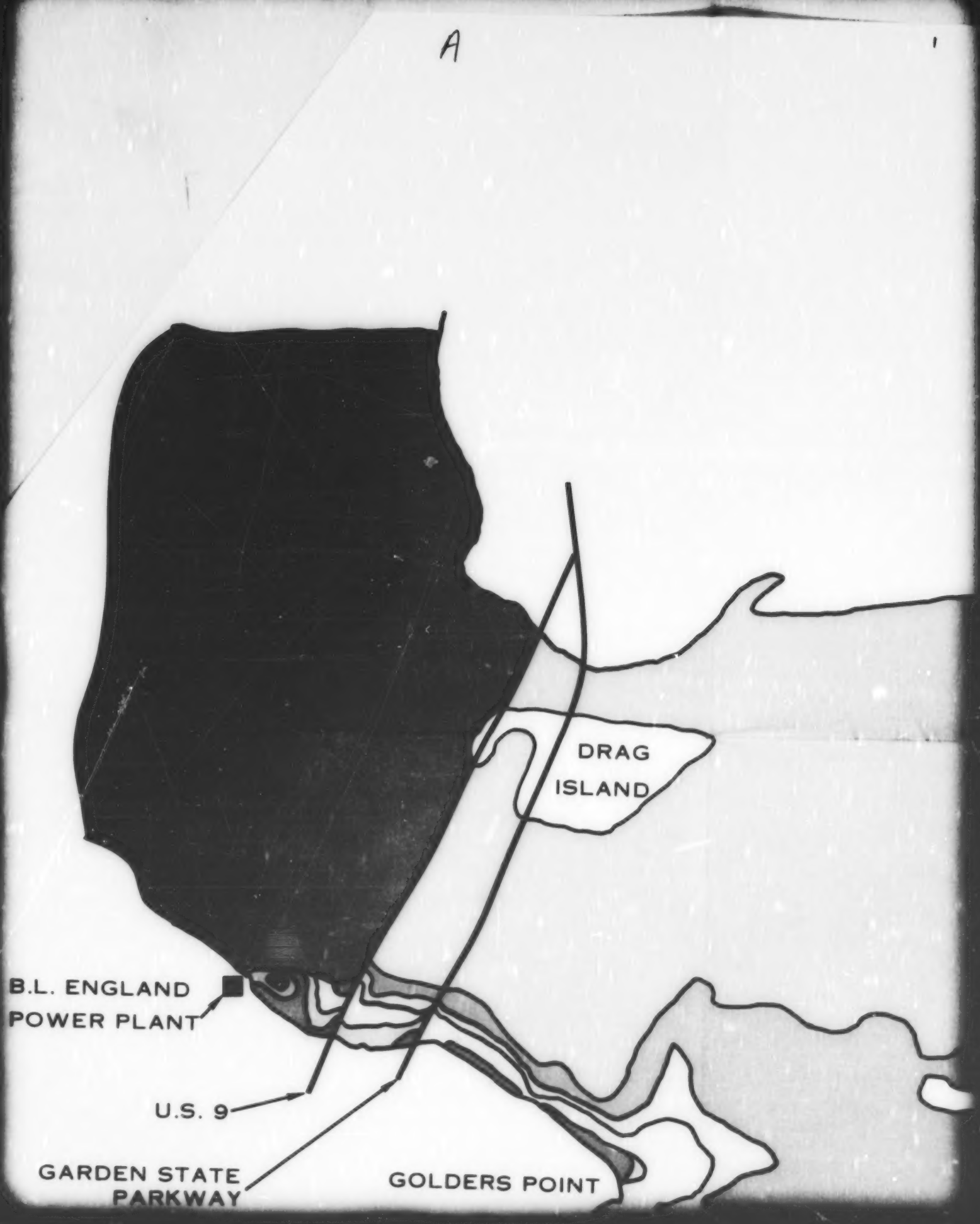
Applicable water quality standards for Great Egg Harbor Bay specify the same temperature criteria as for Barnegat Bay.

The maximum temperature limit of 29.4°C (85°F) was exceeded at only

Great Egg Harbor River
Great Egg Harbor
North
Tuckahoe River
B. L. England Generating Station
Thermal Field
Ocean City

FIGURE 14 Thermal Map, Great Egg Harbor (High Altitude)

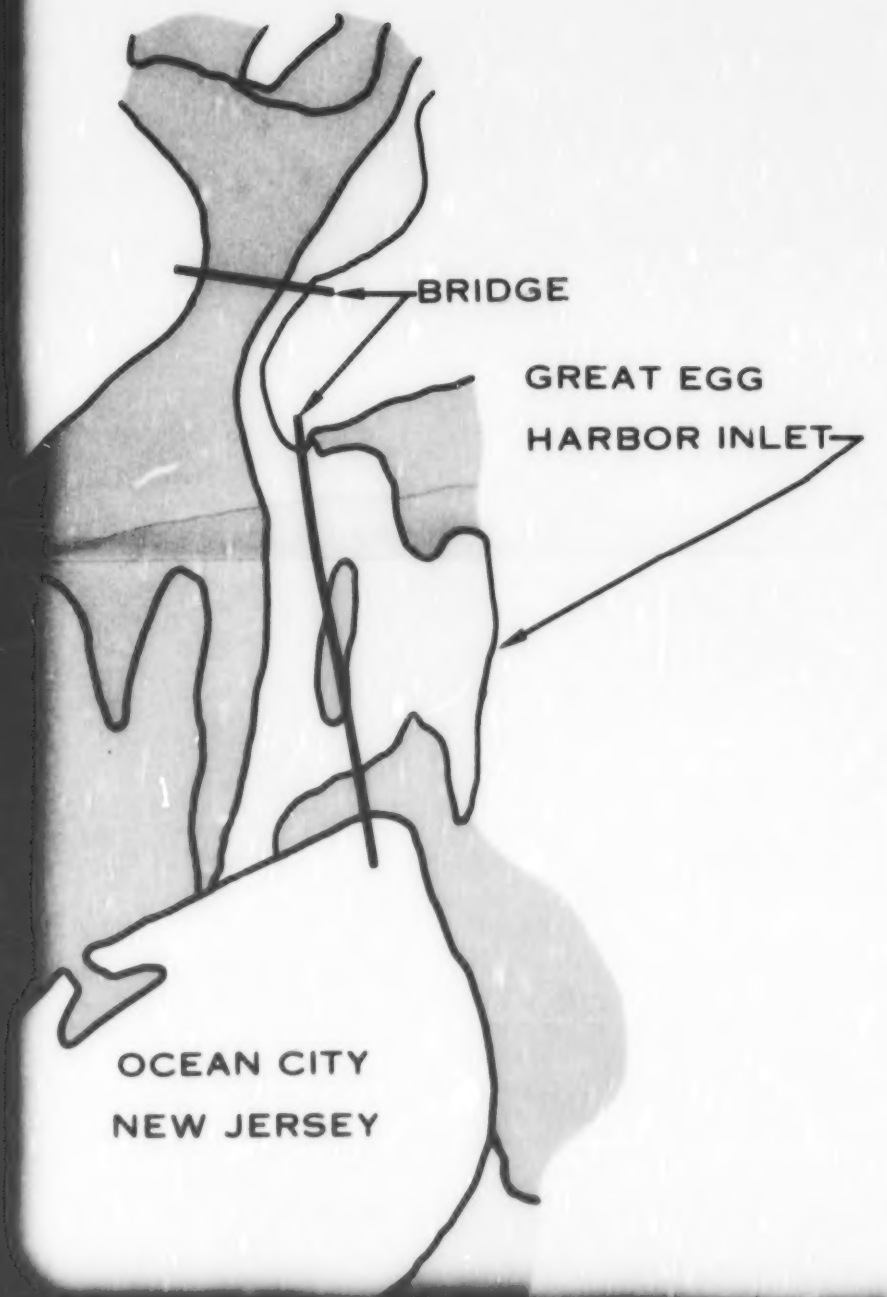
A


DRAG
ISLAND
B.L. ENGLAND
POWER PLANT
U.S. 9
GARDEN STATE
PARKWAY
GOLDERS POINT

B
RAINBOW
ISLANDS
RAINBOW
THORO
COWPENS
OCEAN
NEW JE

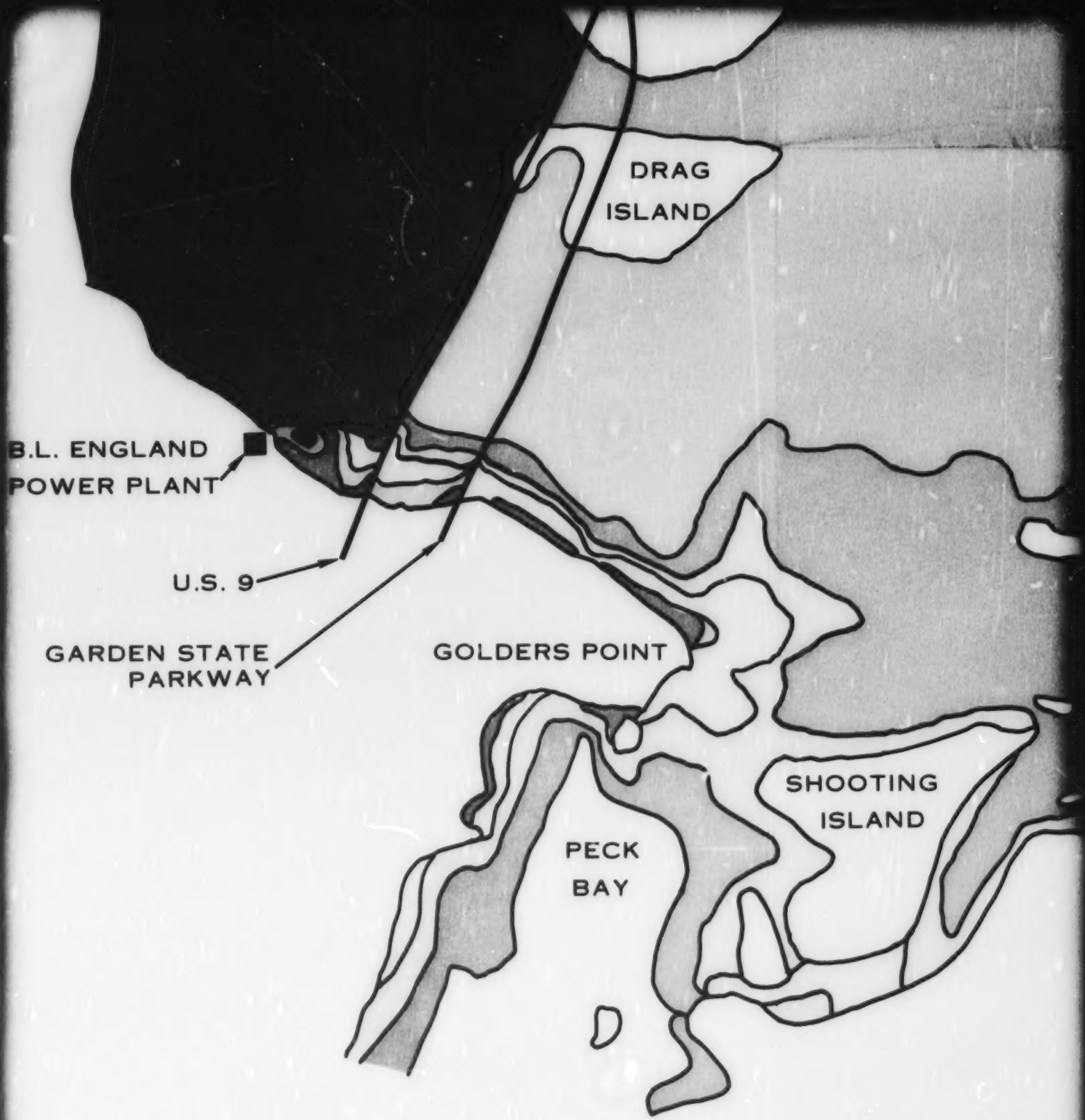
C

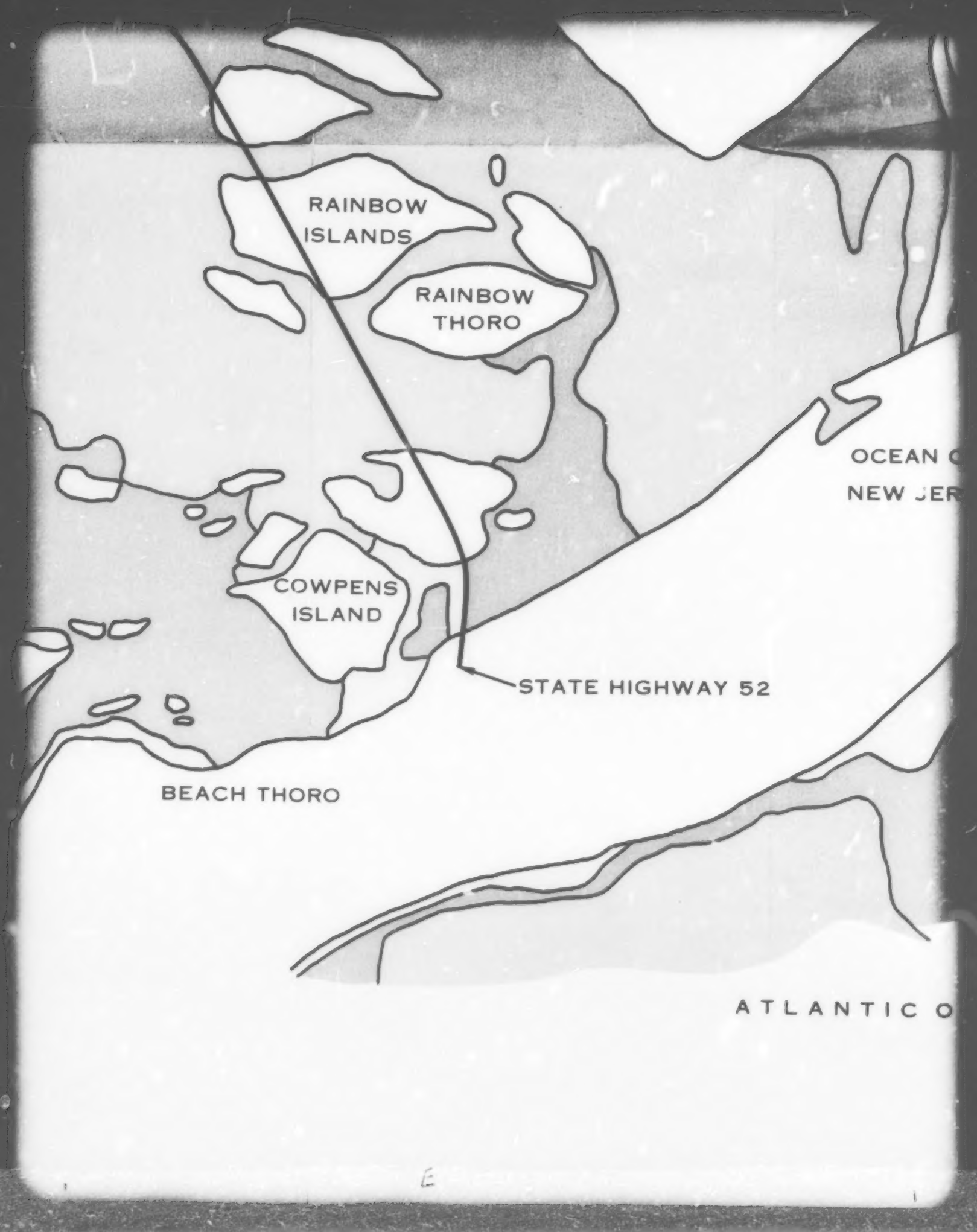
351

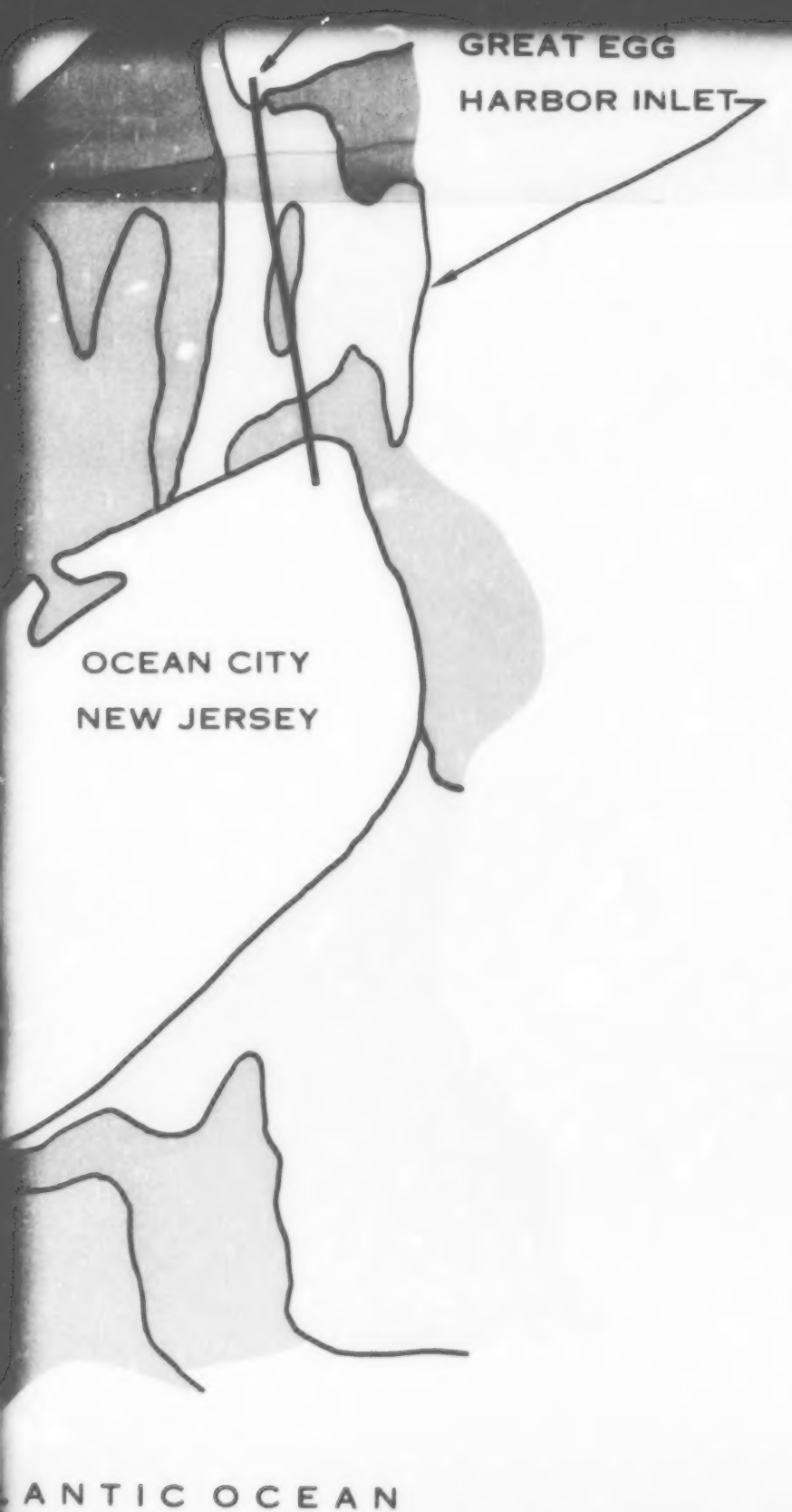


LEGEND

1.		29.5° C
2.		28.5° C
3.		28.0° C
4.		27.5° C
5.		27.0° C
6.		26.5° C
7.		26.0° C
8.		25.5° C
9.		23.5° C
10.		22.8° C


DRAG
ISLAND
B.L. ENGLAND
POWER PLANT
U.S. 9
GARDEN STATE
PARKWAY
GOLDERS POINT
SHOOTING
ISLAND
PECK
BAY


RAINBOW
ISLANDS
RAINBOW
THORO
OCEAN C
NEW JER
COWPENS
ISLAND
STATE HIGHWAY 52
BEACH THORO
ATLANTIC O



1.		29.5° C
2.		28.5° C
3.		28.0° C
4.		27.5° C
5.		27.0° C
6.		26.5° C
7.		26.0° C
8.		25.5° C
9.		23.5° C
10.		22.8° C

Figure 15. Isothermal Map of Great Egg Harbor

F

one point, the red area at the cooling water discharge point [Figure 13]. All other areas were cooler.

In applying the proposed "two-thirds surface" guideline, a selection of the cross-sectional area to be evaluated must be made. Three such cross-sections were selected between Drag Island and the south shore of Great Egg Harbor Bay. These cross-sections are defined by the pairs of arrows numbered 1, 2 and 3 in Figure 13. The No. 1 cross section extends from near the power plant to Drag Island. As the thermal plume hugs the south shore in this area, warm water with temperatures more than 0.8°C above ambient occupy only 21 percent of the surface distance between the arrows. Although in the plume the surface temperatures substantially exceed ambient, the "two-thirds surface" guideline is satisfied. At cross-section No. 2, the thermal field completely fills the surface of the Bay from the south shore to Drag Island which is not within the proposed guidelines. The thermal field also completely fills the distance along cross-section No. 3 but 28 percent of the distance is in the blue area (Isotherm No. 9) that is less than 0.8°C above ambient. The remaining 72 percent of the surface is not within the "two-thirds surface" guideline.

At slack tide the thermal plume would be expected to extend further offshore than the observed plume during an ebb tide. Thus, non compliance with the proposed guideline along cross-section No. 1 might also occur. Flood tide conditions would produce upstream movement of the plume with unknown effects with respect to the standards.

Examining the mouth of Peck Bay between Shooting Island and

Colders Point [Figure 13] it is obvious that the plume completely fills the surface of this cross-section which is not within the proposed guideline.

Isotherms Nos. 5, 6 and 7 [Figure 13] are substantially above ambient temperatures. These areas occupy more than 4 sq km (1.5 sq mi) of central Great Egg Harbor Bay indicating that under ebb tide conditions much of the thermal plume extends into this area. This large plume may not be within the proposed guideline in this area.

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